RESULTS AND DISCUSSION

Conventional Parameters

Conventional parameters are the physical and chemical measurements that help to define the characteristics of the aquatic environment. The following discussion includes these conventional parameters: flow, dissolved oxygen, temperature, turbidity, total suspended solids, pH, and conductivity.

Flow

Stream flow greatly influences the character of a stream and is an important parameter for understanding stream water quality. It is well known that increased impervious surfaces result in increased stormwater runoff, which then leads to increased stream bank erosion, habitat degradation, and decreased low flow conditions. Though one of the smaller drainage basins, the suburbanized Juanita Creek watershed has relatively high wet weather and stormwater flows (Figure 3). It has been consistently demonstrated that a sharp threshold in habitat quality exists at approximately 10 to 15 percent imperviousness within the drainage basin (Schueler and Holland, 2000a). Monitoring and modeling studies have consistently indicated that urban pollutant loads are directly related to watershed imperviousness.

Impervious surfaces also prevent rainwater from infiltrating into the soil and consequently diminish groundwater recharge. Decreased groundwater supplies can result in decreased water levels in dry weather with serious implications for habitat quality (Schueler and Holland, 2000b).

While flow measurements are important for calculating pollutant loading and determining the relative impact of a pollutant on the receiving water body, water quality standards and pollution indices are based upon the *concentration* of the parameter measured. Therefore, the following discussion is focused on measured concentrations.

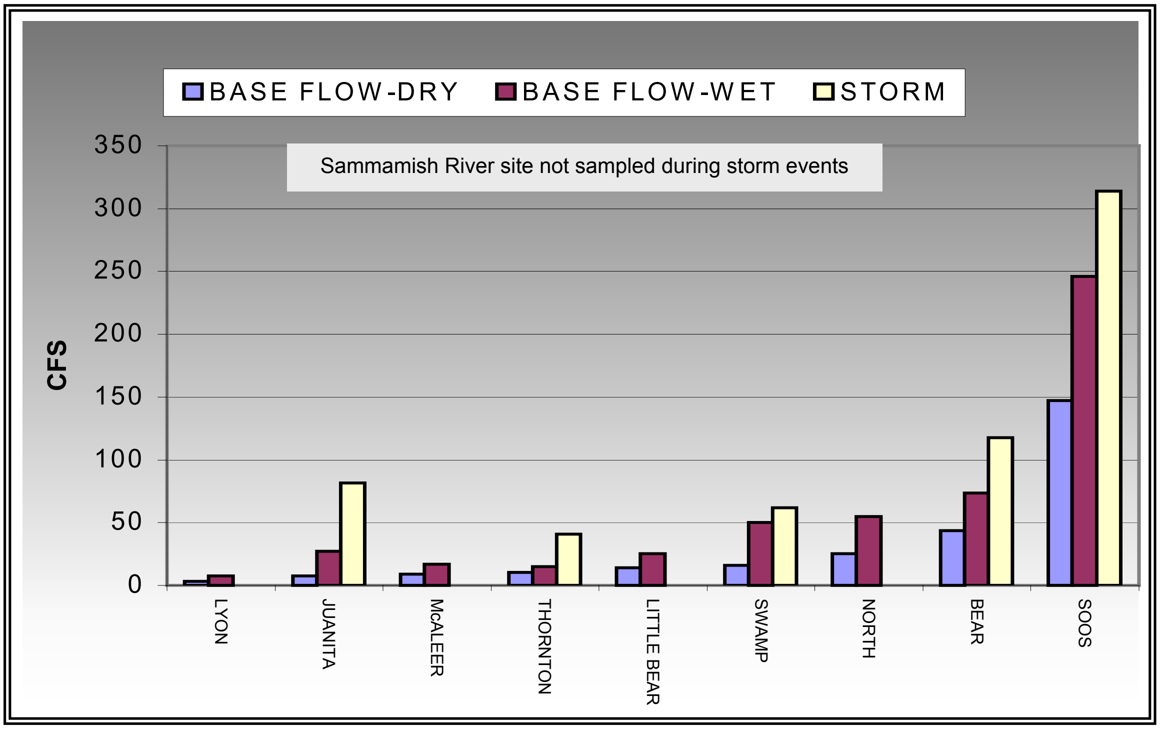

Figure 3. Average Flows from Baseline Wet and Dry Season Measurements (1979 – 1999), and Storm Event Measurements (1987 – 1999) at the mouth of each creek. Streams are ranked in order of drainage area size with Lyon Creek being the smallest (see Table 1). Flows were not measured at the mouth of the Sammamish River.

Dissolved Oxygen

Dissolved oxygen is important to many of the chemical processes that are important in the aquatic environment. The concentration of dissolved oxygen is also important in determining the amount of habitat available for different types of aquatic organisms. The state standard for Class AA waters specifies that concentrations shall exceed 9.5 mg/L.

Baseline versus Storm - At most sites dissolved oxygen concentrations fell below the state standard of 9.5 mg/L in less than 5 percent of the baseline measurements (Table 3, Figure 4). Only these four sites had measurements below the state standard more frequently: the mouth of Swamp Creek (0470), Sammamish River at Kenmore (0450), the mouth, and upstream Evans Creek (B484 and S484). In the storm samples only one site had values below the state criteria. Three of the 26 storm samples (12 percent) collected from the mouth of Swamp Creek (O470) had dissolved oxygen concentrations below the state criteria. (The mouth of the Sammamish River (Kenmore 0450) is not sampled during storm events.)

Table 3. Summary of Dissolved Oxygen Concentrations in Baseline and Storm Measurements

Dissolved Oxygen (mg/L)	Baseline (n=4,574)	Storm (n=313)
Overall Mean (all sites)	10.5	10.5
Range of Site Means	9.3 – 11.3	9.9 – 10.8
% of Total Not Meeting Criteria	2.5 %	1.0 %

Eleven percent of the baseline measurements taken at Kenmore near the mouth of the Sammamish River (0450) were substandard, primarily during the dry summer season. This station frequently has high water temperatures (28 percent exceeded the temperature standard as discussed below) and warmer temperatures result in less dissolved gases in the water column. This site area backwater from Lake Washington when flows from the Sammamish River are low. Slower movement of the water through the area contributes to warmer water temperatures as well as lower dissolved oxygen concentrations. During warm weather, heavy recreational boat use also occurs in the area and sediments may become resuspended by boat traffic. Suspended sediments may also influence dissolved oxygen levels through sediment oxygen demand. In addition, the Kenmore interceptor has occasionally overflowed into this area adding organic material to the sediment increasing the sediment oxygen demand.

Baseline dissolved oxygen levels at the mouth of Evans Creek (B484) were below state criteria 33 times out of 269 measurement (12 percent), with the lowest value being 5.3 mg/L recorded on May 12, 1997. Dissolved oxygen concentrations upstream on Evans Creek (S484) were low 20 times (7 percent) over the same period with the lowest level measured at 2.3 mg/L on September 14, 1998. Low values at both the upstream and downstream sites on Evans Creek occurred during the dry season, but not during storm events necessarily on the same day.

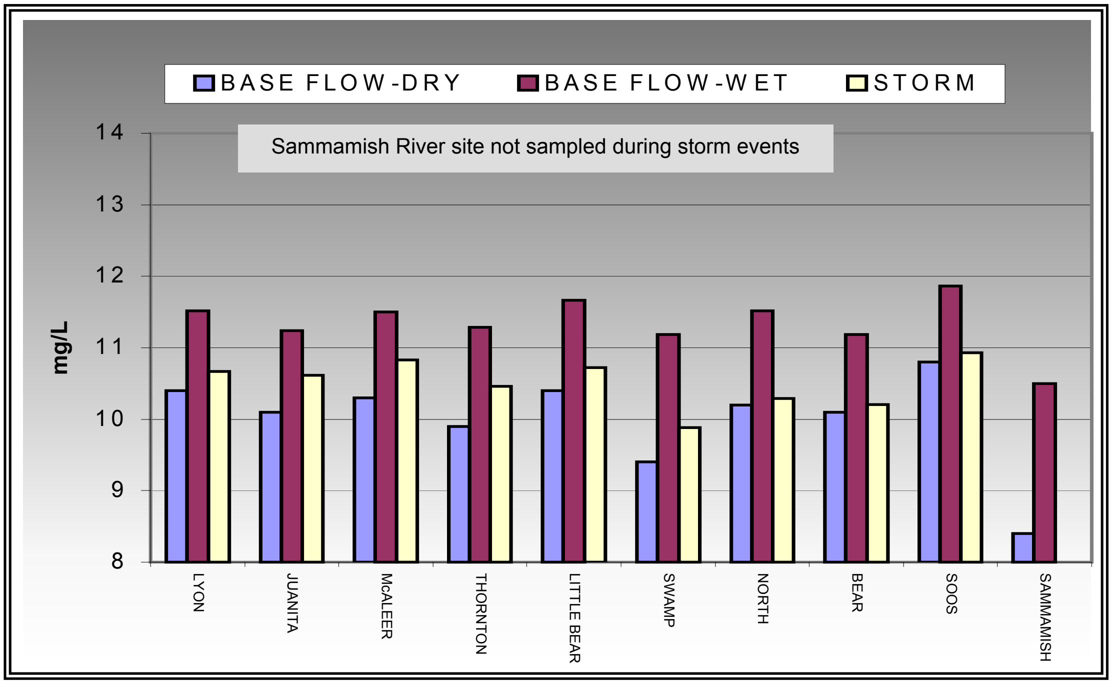

Figure 4. Average Dissolved Oxygen Concentrations for Baseline Wet and Dry Season Measurements (1979 – 1999), and Storm Event Measurements (1987 – 1999) at the mouth of each creek. Streams are ranked in order of drainage area size with Lyon Creek being the smallest (see Table 1).

Low dissolved oxygen levels in Evans creek did not significantly impact concentrations downstream in the main stem of Bear-Evans Creek. Only four of the baseline samples from the mouth of Bear-Evans Creek (0484) measured below state criteria over the same twenty-year reporting period.

Wet/Dry Seasons - Average dissolved oxygen concentrations were consistently higher during the wet season (Figure 4). This is to be expected for several reasons. Higher flows and turbulence during the wet season increase the amount of oxygen mixed into the water column. Also, the solubility of this gas in water varies inversely with temperature, as water temperatures rise during the dry season, the capacity of the water to hold oxygen declines.

Trend Analysis: The Kendall's test suggests a trend toward decreasing dissolved oxygen concentrations at only two sites - Evans Creek (B484), and the mouth of Swamp Creek (0470). The time series plots (see Appendix IV) suggest that dissolved oxygen levels dropped significantly at both sites in 1990. Although the dissolved oxygen concentrations at those two sites remain lower than most of the other sites sampled, the time-series plots suggest that the concentrations in Swamp Creek (0470) have gradually been increasing since 1993. The cause(s) of the trends in the dissolved oxygen concentrations at those four sites were not identified

Temperature

Temperature is an important physical parameter for aquatic systems as it influences many of the chemical processes in water (i.e., dissolved oxygen concentration). Temperature also exerts a major influence on biological activity, growth, and therefore ultimately the survival of aquatic organisms. The state standard for temperature for Class AA waters specifies that the temperature shall not exceed 16° Celsius.

Baseline versus Storm: Baseline temperature measurements exceeded the class AA criterion in 36 percent of the measurements at Marymoor Park (0486) and 23 percent at Kenmore (0450). All other stations exceeded the temperature criteria in less than 10 percent of the baseline samples (Table 4, Figure 5). Storm event temperature measurements consistently met the state standard at most sites or exceeded it only once (<5 percent of samples). During storm events, Bear Creek (0484) exceeded the temperature standard twice, Lyon Creek (0430) exceeded the standard twice, and Thornton Creek (0434) exceeded the standard three times.

Table 4. Summary of Temperature Values in Baseline and Storm Measurements

Temperature (°C)	Baseline (n=4,940)	Storm (n=328)
Overall Mean (all sites)	10.62	9.71
Range of Site Means	9.56 – 13.39	9.23 – 10.42
% of Total Not Meeting Criteria	7.7 %	3.1 %

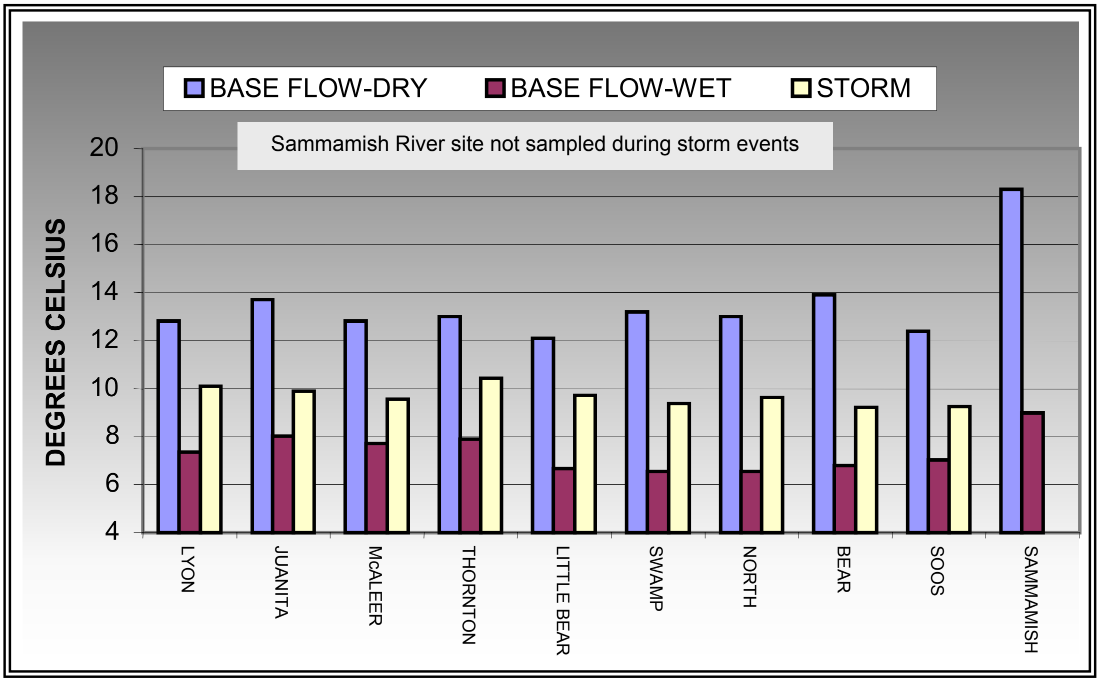

Figure 5. Average Temperatures for Baseline Wet and Dry Season Measurements (1979 – 1999), and Storm Event Measurements (1987 – 1999) at the mouth of each creek. Streams are ranked in order of drainage area size with Lyon Creek being the smallest (see Table 1).

At Marymoor Park, temperature is essentially the same as the surface waters of Lake Sammamish. At Kenmore, the river is wide and sluggish with little cover; consequently, water temperature is high. High temperatures are the primary cause of sub-standard dissolved oxygen levels (see above discussion). Though baseline temperature measurements were high at both Sammamish River stations, measurements at Marymoor were significantly higher than downstream at the mouth of the river at Kenmore (0450).

Wet/Dry Seasons. Average temperatures were 5.8 °C higher in the dry season (April – September) than in the wet season (October–March) (Figure 5).

Trend Analysis. The Kendall's test results suggest that temperatures at eighteen of the twenty sites have been increasing over the twenty-year period of record. The two sites not exhibiting an increasing trend are Covington Creek (C320) in the Soos Creek drainage basin and the mouth of Juanita Creek (C446). Whether this increase is indicative of regional climatic changes, a response to the removal of riparian vegetation, or some other long-term cycle has not been determined. However, it is interesting to note that no temperature increases were detected for the same period of record at the two sites on the upper Green River (A319 and B319). (Several sites in the Green River drainage basin are also routinely sampled (King County WLRD, unpublished data).. Both of these upper Green River sites are in areas that have seen little or no development within the watershed. This may indicate that the trend in increasing temperature noted at the nineteen sites may not be solely in response to regional climatic variability, but could be related to land cover changes associated with urbanization.

Turbidity and Total Suspended Solids

Turbidity and total suspended solids (TSS) are two indicators used to estimate the amount of suspended material in the water, whether it is mineral (e.g., soil particles) or organic (e.g., algae). Particulate matter provides attachment places for pollutants such as metals or bacteria to enter the receiving water. High concentrations of particulate matter can result in increased sedimentation that can impair important habitat for fish and invertebrates. In general, it is human activities within the watershed that usually results in higher turbidity and TSS measurements (e.g., development results in loss of vegetation, increased erosion, and runoff).

Turbidity is measured as the amount of light scattered in a water sample and is reported as nephelometric turbidity units (NTU) (Table 5, Figure 6). The more material in the water, the greater the light scattering and higher NTU reading. The state Class AA turbidity criterion is used primarily for assessing the impact of point discharges.

TSS is a measure of the actual weight of material per volume of water and is reported in milligrams per liter (Table 6, Figure 7). This measurement becomes important when trying to calculate total quantities of material in a stream, or when trying to determine the loading of particulate matter into receiving waters. There is no state water quality standard for TSS.

Usually, when using turbidity to evaluate the impact of a pollutant source, two measurements are made - one upstream of a discharge point (background levels) and another downstream. The Class AA criteria states, “downstream turbidity shall not be more than 5 NTU higher than the upstream measurement if the background is 50 NTU or less.” In this monitoring program, measurements are made at only one point in a stream and typically were less than 50 NTU in baseline measurements. To evaluate potential turbidity problems at each site, individual measurements were compared to the average of all measurements for that site. Values exceeding the average by 5 NTU or more were considered sub-standard.

Turbidity

Baseline versus Storm. The frequency of substandard turbidity levels measured in baseline samples (as defined above) ranged from less than one percent at Covington Creek (C320) in the Soos Creek drainage to nearly twelve percent at the mouth of Juanita Creek (0446) (Table 5, Figure 6). During storm events, turbidity levels at most sites exceeded the standard of 5 NTU over background levels about 25% of the time. Storm samples collected at the mouth of Little Bear Creek (0478) exceeded this standard roughly 68% of the time.

Table 5. Summary of Turbidity Values in Baseline and Storm Measurements

Turbidity NTU	Baseline (n=4,800)	Storm (n=330)
Overall Mean (all sites)	3.34	16.0
Range of Site Means	1.75 – 5.49	8.5 – 19.9
% of Total Not Meeting Criteria	5.3 %	23.3 %

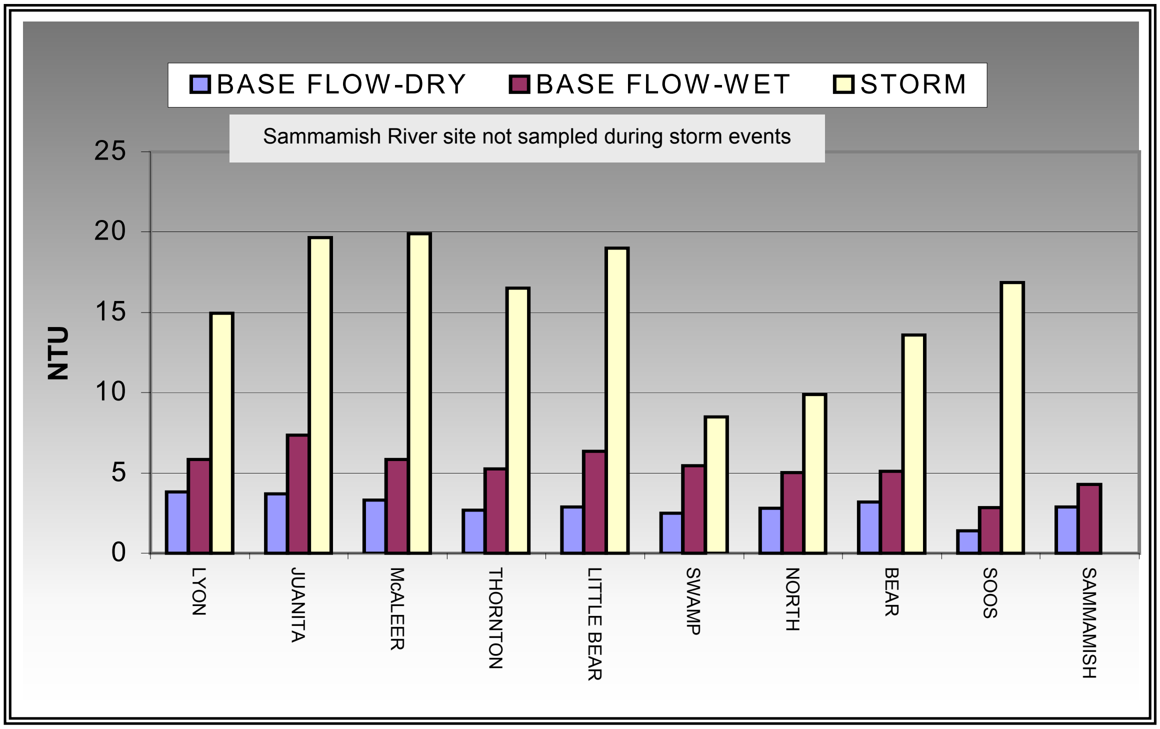

Figure 6. Average Turbidity for Baseline Wet and Dry Season Measurements (1979 – 1999), and Storm Event Measurements (1987 – 1999) at the mouth of each creek. Streams are ranked in order of drainage area size with Lyon Creek being the smallest (see Table 1).

Wet/Dry Seasons. Wet season turbidity levels were roughly twice as high as dry season levels. Higher flows and turbulence during the wet season keep fine solids in suspension resulting in higher turbidity. The dry season/wet season turbidity averages were 2.9 NTU (n=2386) and 5.4 NTU (n=2416), respectively.

Trend Analysis. Because this parameter is so variable, trends were difficult to discern on the time-series plots. The Kendall's test detected no trends.

Total Suspended Solids (TSS)

Baseline versus Storm. Only five sites had average baseline TSS concentrations exceeding 10 mg/L - Juanita Creek (sites 0446 and C446), Lyon Creek (0430), McAleer Creek (A432), and Little Bear Creek (0478) (Table 6, Figure 7). These five sites are in basins that have undergone extensive urbanization in the last twenty years. The exact source of the higher suspended solid concentrations (i.e., poor construction practices, increased erosion from stream channelization, etc.) was not specifically determined.

Average storm TSS concentrations were roughly seven times higher than baseline averages. Juanita Creek (0446) had the highest storm average (105.6 mg TSS/L, n=47) and the highest measured value during a storm event (2,487 mg TSS/L). Without this single high value in the database, the average for all storm samples would have been 47 mg TSS/L and the Juanita Creek average would have been 54 mg TSS/L – approximately half as high. A similar situation exists for site A320 at the mouth of Soos Creek where the storm average was 65.8 mg TSS/L but would have been 43.5 mg TSS/L without a high sample concentration of 1,092 mg TSS/L measured on one occasion. These two examples illustrate the potential impact just one sample can have on the interpretation of water quality data and demonstrates the need to analyze data using several statistical tools. While only one extreme value was sampled, it can be assumed that these transitory events occur more frequently.

Table 6. Summary of Total Suspended Solid Concentrations in Baseline and Storm Measurements		
Total Suspended Solids (mg/L)	Baseline (n=4,817)	Storm (n=330)
Overall Mean (all sites)	7.6	55.0
Range of Site Means	3.7 – 13.3	21.4 – 105.6
% of Total Not Meeting Criteria	Not applicable	Not applicable

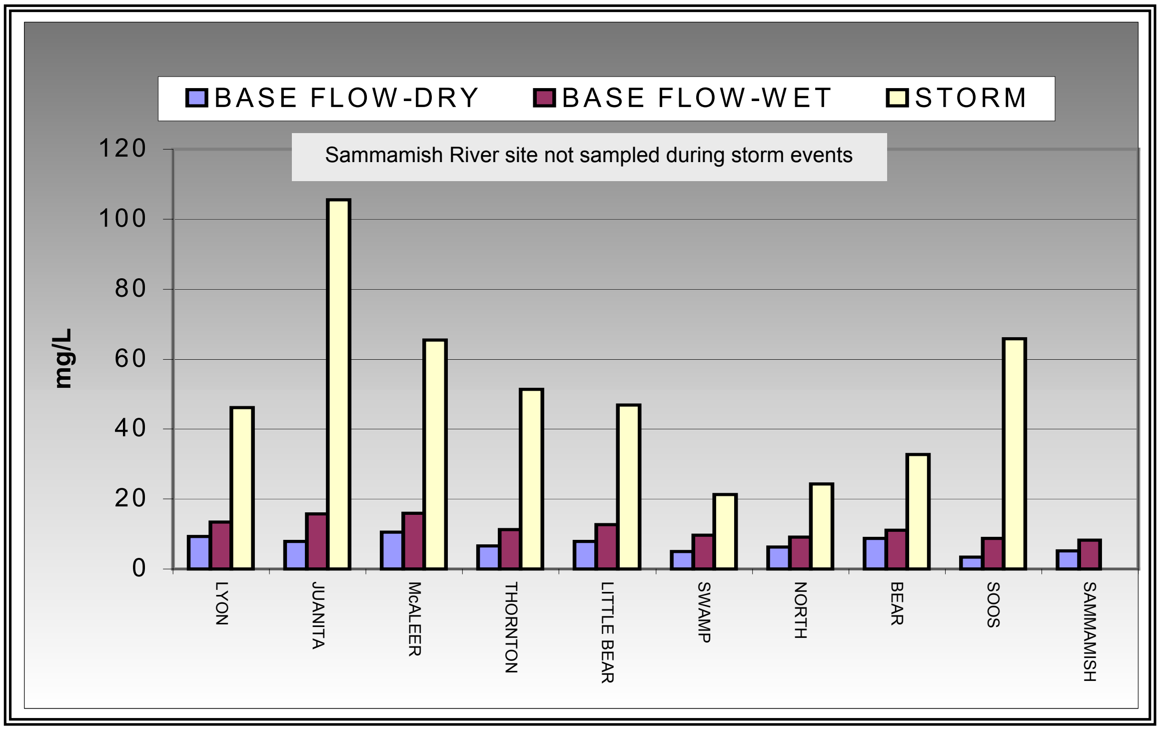

Figure 7. Average Total Suspended Solids for Baseline Wet and Dry Season Measurements (1979 – 1999), and Storm Event Measurements (1987 – 1999) at the mouth of each creek. Streams are ranked in order of drainage area size with Lyon Creek being the smallest (see Table 1).

The result of the Spearman's Rho test (where the percent increase from dry season to wet season for both turbidity and TSS at the nine storm sites were ranked), confirms that turbidity and TSS are linked during the wet season. There was no correlation between turbidity and TSS with the dry season data. During the dry season, mineral particles tend to settle out onto the streambed leaving the colloids and both living and dead organic material suspended in the water column. Both of these materials tend to be much less dense than the mineral particles resulting in turbidity measurements being relatively higher than TSS concentrations.

Trend Analysis. Time-series plots at many sites suggest that the baseflow TSS concentrations have been decreasing over the period of record. However, the only statistically significant declining trend was on the Little Soos Creek (G320). The decline in suspended solids in Little Soos Creek may be the result of changes in land use a short distance upstream from the sampling site where small hobby farms no longer keep livestock.

pH

The pH of water is a measure of the concentration of hydrogen ions (H^+). A value higher than seven (meaning there are fewer free hydrogen ions) is considered basic, pH of seven is considered neutral, and a pH less than seven is considered acidic. The pH of water determines the solubility and biological availability of chemical constituents such as heavy metals and nutrients. Metals tend to be more toxic at lower pH values because they are more soluble. Likewise, at lower pH values, nutrients are also in soluble form and are therefore more readily available for take up by aquatic plants. If nutrients enter a water body in the form of organic matter that first needs to be broken down before it can be utilized for growth by plants, pH affects the rate of decomposition.

The state Class AA standard for pH is between 6.5 and 8.5. Any values outside this range violate the criteria.

Baseline versus Storm. Baseline pH at most sites was almost always within the state criteria range of 6.5 to 8.5 (Table 7, Figure 8), with low measurements down to 6.1 on occasion. Storm event pH measurements were within the state criteria range of 6.5 to 8.5 in all but four samples. Two storm samples collected at the mouth of Swamp Creek, and one each from the mouth of Bear-Evans and North Creeks had pH measured between 6.2 and 6.5

Photosynthetic activity of algal blooms in Lake Sammamish, just upstream from the sampling site at Marymoor (0486), result in higher pH levels in the lake and subsequently influence pH levels at this site. The pH at Marymoor was above 8.5 roughly 10% of the time.

Table 7. Summary of pH values in Baseline and Storm Measurements

pH	Baseline (n=4,425)	Storm (n=305)
Overall Mean (all sites)	7.35	7.17
Range of Site Means	7.13 - 7.73.3	7.15 - 7.47
% of Total Not Meeting Criteria	1.1 %	1.3 %

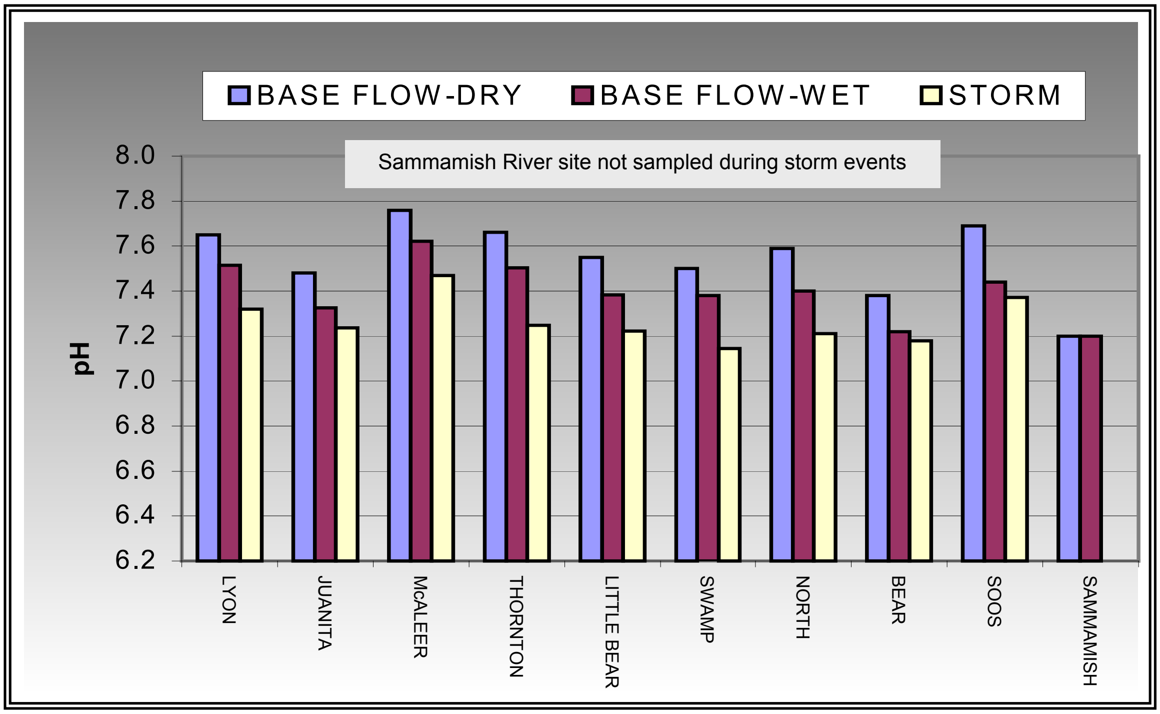

Figure 8. Average pH for Baseline Wet and Dry Season Measurements (1979 – 1999), and Storm Event Measurements (1987 – 1999) at the mouth of each creek. Streams are ranked in order of drainage area size with Lyon Creek being the smallest (see Table 1).

Wet/Dry Seasons. pH exhibits seasonality with levels lowest October through December, perhaps a result of increased stormwater runoff and a decrease in photosynthetic activity with the decrease in daylength and subsequent reduction in sunlight. The highest pH occurs in April, May and June when algae growth occurs both in lakes and streams. The pH averages were between 0.15 and 0.20 units lower in the wet season than the dry season.

Trend Analysis. Statistically significant decreasing trends in pH were detected for sites on Thornton Creek (0434), the Sammamish River at Kenmore (0450), Swamp Creek (0470), McAleer Creek (A432) and both sites on Evans Creek (B484, mouth, and S484 upstream). Increased urbanization and the resulting increased stormwater runoff may have contributed to the decrease in pH. Non-urbanized wetlands in the Puget Sound region tend to be slightly acidic (e.g., lower pH) (Schueler and Holland, 2000d). When wetlands are disturbed through urbanization the pH in nearby tributaries could drop as the more stormwater runoff is flushed through the wetland. Specific causes for the decreasing pH trend was not investigated.

Conductivity

Conductivity is a measure of the passage of electric current through water. Resistance is expressed as ohms while conductivity is expressed as mhos - the opposite spelling. The concentration of dissolved ions in water largely determines its conductivity. Water in the Puget Sound region generally has low levels of dissolved minerals and relatively low conductivity compared to regions with higher concentrations of dissolved minerals in the water. Increases in conductivity can indicate the presence of dissolved ions potentially from a pollutant source (e.g., nitrite-nitrate from fertilizers).

Baseline versus Storm. Baseline conductivity measured in the streams was within the norm for the Puget Sound region (Table 8, Figure 9). Baseline conductivity in Little Soos Creek (G320) was the lowest with an average of 60.5 μmhos. The average baseline conductivity at Bear Creek at Seidel Rd. (J484) was also relatively low at 87 μmhos. At most storm sampling sites, stormwater conductivities were lower than baseflow measurements with the exception of the mouth of Bear-Evans Creek (0484) and Soos Creek (A320).

Table 8. Summary of Conductivity Values in Baseline and Storm Measurements

Conductivity (μmhos)	Baseline (n=4,806)	Storm (n=327)
Overall Mean (all sites)	135	119
Range of Site Means	87 – 225	106 - 149
% of Total Not Meeting Criteria	Not applicable	Not applicable

Wet/Dry Seasons. Conductivity exhibits seasonality with the lowest in February and highest in August. Conductivity also appears to be related to different forms of nitrogen that varies between the seasons and storm samples. Those relationships are discussed in the nutrient section below.

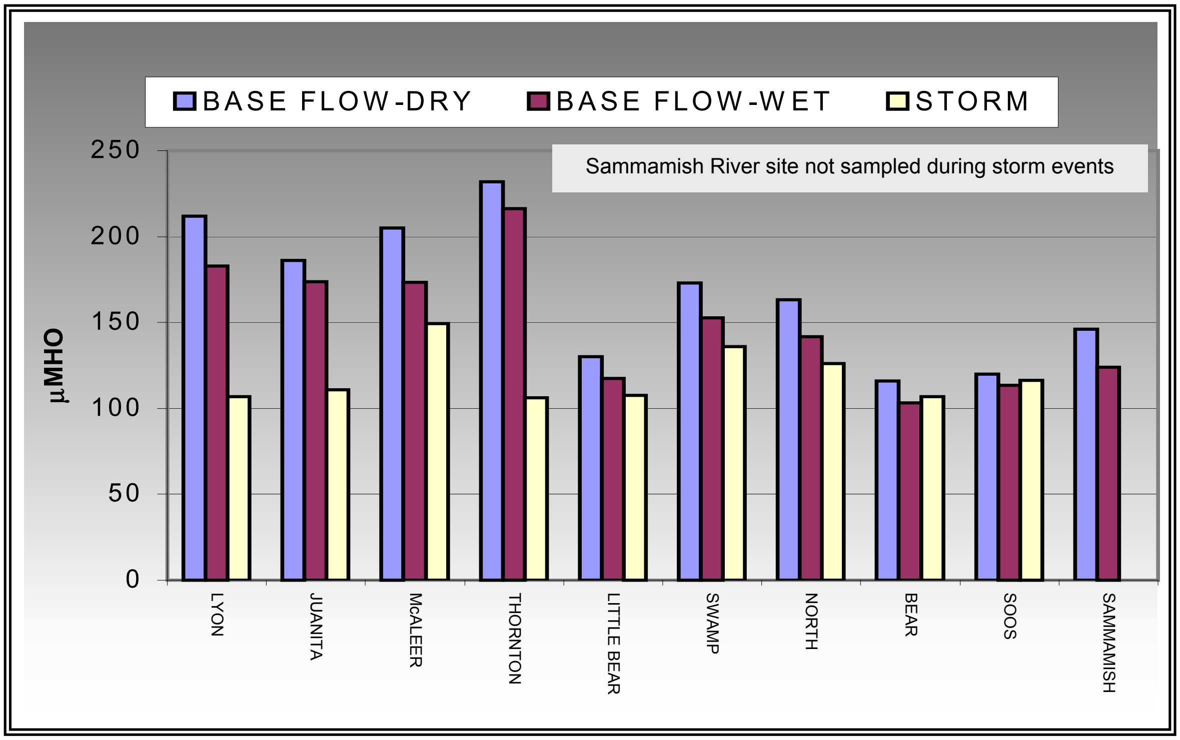

Figure 9. Average Conductivity for Baseline Wet and Dry Season Measurements (1979 – 1999), and Storm Event Measurements (1987 – 1999) at the mouth of each creek. Streams are ranked in order of drainage area size with Lyon Creek being the smallest (see Table 1).

Trend Analysis. All of the sites in this report, except upper Evans Creek (S484), show a significant increasing trend in conductivity over the 20-year reporting period. At most sites, the conductivity gradually increased by about 20 µmhos from 1979 to 1999. Conductivity at the mouth of Soos Creek increased by about 50 µmhos, as did the levels in two of its primary tributaries, Covington, and Jenkins Creeks. Residential development in those sub-basins has been intense, particularly in the last ten years. The increases at Thornton Creek (0434) and in Little Soos (G320) were less but still significant. No increases in conductivity have been noted in the upper reaches of either the Green River (sites A319 and B319) or the Cedar River (A438) (King County WLRD, unpublished data). Urban development in these upper river watersheds has been relatively light compared to other sampling sites discussed in this report. While conductivity seems to be linked to flows and land use changes, the impact on the in-stream habitat is unknown.

Conductivity and Alkalinity

Alkalinity (expressed as mg/L $CaCO_3$) is a measure of the buffering capacity of water. In other words, the greater the alkalinity, the more resistant the system is to a change in pH. Between the pH ranges of 6 – 8, alkalinity is primarily due to the presence of bicarbonate (HCO_3^-). In freshwater, conductivity is primarily influenced by $CaCO_3$, most of which is derived from weathering rocks. Both conductivity and alkalinity are measured routinely in the baseline samples. To determine if the link between these two parameters was similar at the stream sites, a limited database (twelve streams and three river sites) was assembled (Table 9).

Table 9 Conductivity versus Alkalinity Comparison Statistics for Twelve Streams and Three River Sites

Locator	Slope	Y-intercept	R^2	n=
Bear-Evans Creek	1.63	43.3	0.82	44
Coal Creek	2.29	68.7	0.87	44
Forbes Creek	1.79	46.9	0.87	50
Juanita Creek	2.28	24.3	0.86	45
Kelsey Creek	2.00	33.6	0.83	46
Little Bear Creek	1.68	52.2	0.75	54
Lyon Creek	2.26	29.5	0.83	46
May Creek	2.03	39.7	0.84	42
McAleer Creek	2.24	32.9	0.81	50
North Creek	1.56	63.4	0.56	44
Swamp Creek	1.73	55.1	0.67	48
Thornton Creek	2.43	24.8	0.90	45
Sammamish River				
Marymoor	1.60	38.8	0.31	43
Kenmore	1.81	41.3	0.80	42
Cedar River	2.25	4.1	0.93	41
All Sites Combined	**2.52**	**7.8**	**0.92**	**684**

Overall, the data suggest that the relationship between alkalinity and conductivity is unique to each stream site. The greater the R^2 value, the more likely that $CaCO_3$ rather than some other dissolved ion (i.e., nitrate+nitrate-nitrogen) is influencing conductivity at that site. Monitoring data for departures from the conductivity - alkalinity relationship observed at each stream may be an inexpensive method for detecting changes in water quality resulting from land use change or some source of dissolved contaminants.

The conductivity and alkalinity data from Marymoor is unlike other stream sites. The Marymoor sight is outflow from Lake Sammamish a short distance upstream and the water chemistry similar to a lake rather than a typical stream in this region.

Nutrients

Nitrogen and phosphorus are monitored in the streams because of their potential impact on the phytoplankton (algae) populations in Lakes Sammamish, Washington and Union, and ultimately Puget Sound, as well as in-stream biota. A "*limiting nutrient"* is the nutrient least available relative to other nutrient demand required for plant growth. Algal production is restricted by the relative supply of nitrogen and phosphorus and their presence in high or increasing concentrations is usually indicative of human impact to the environment. In most lakes in this region, the limiting algae nutrient is phosphorus.

Both nutrients can be measured in several forms. For the baseline and storm samples, nitrogen was measured as total nitrogen (TN), nitrite + nitrate-nitrogen (NO_3-NO_2), and ammonia-nitrogen (NH_4). Phosphorus was measured as total phosphorus (TP) and orthophosphate (ortho-P).

Nitrogen (Ammonia, Nitrate+Nitrite, Total Nitrogen)

Total nitrogen includes the other measured forms, plus organic nitrogen. The two forms of inorganic nitrogen (ammonia-nitrogen and nitrate+nitrite-nitrogen) are highly soluble in water and are components of fertilizers, sewage effluents, and manure. The relative percentages of each of the nitrogen components can provide information of the potential source of pollution. The percentages of the different nitrogen forms were fairly consistent in the baseline monitoring at all stream sites and are summarized below in Table 10.

Ammonia (NH_4)

Ammonia-nitrogen is generated by heterotrophic bacteria as the primary end product of decomposition of organic matter. Although intermediate nitrogen compounds are formed in the progressive degradation of organic material, these rarely accumulate and are deaminated rapidly by bacterial utilization. Although ammonia is a major excretory product of aquatic and terrestrial animals, in the normal aquatic environment the majority of ammonia-nitrogen is formed through decomposition.

Table 10. Nitrogen forms and their relative percentages found in the baseline stream samples.		
Nitrogen Form	**Concentration (mg/L)**	**Percent of total**
Total-N	1.17	100
Organic-nitrogen	0.28	24
Nitrate + nitrite	0.86	74
Ammonia - nitrogen	0.03	2

Ammonia in water is present primarily as NH_4^+ and as un-ionized NH_4OH, the latter being highly toxic to many organisms, especially fish. The proportions of NH_4^+ to NH_4OH are dependent on pH and, to a lesser extent temperature. The approximate ratios of NH_4^+ to NH_4OH (Hutchinson, 1957) are shown in Table 11 below.

Table 11. Ratio of NH_4^+ to NH_4OH at different pH levels.	
pH	**Ratio of NH_4^+ : NH_4OH**
6.0	3000:1
7.0	300:1
8.0	30:1
8.5	3:1

Ammonia gas (NH_3) is the form of most immediate concern because of its toxicity. However, the proportion of the total ammonia that becomes free gas is limited by pH. As the pH increases, so does the NH_3 fraction. The slightly acid to nearly neutral pH of the waters in this region drastically reduces the toxic fractions so total ammonia concentrations need to be $\geq$ 4mg/L before ammonia gas would become a threat. There have been no measurements of ammonia at or above that level in samples included in this report.

Baseline versus Storm. Ammonia-nitrogen concentrations were higher in storm samples than baseline samples at most sites (Table 12, Figure 10). The highest ammonia concentration measured was 1.700 in a storm sample from Bear Creek (0484).

Table 12. Summary of Ammonia Concentrations in Baseline and Storm Measurements.

Ammonia-N (mg/L)	Baseline (n=3,966)	Storm (n=287)
Overall Mean (all sites)	0.03	0.066
Range of Site Means	0.017 – 0.048	0.006 – 1.700
% of Total Not Meeting Criteria	Not applicable	Not applicable

Wet/Dry Seasons. Ammonia-nitrogen levels in both seasons were relatively low but the wet season average concentration was nearly double the dry season average at McAleer, North, Little Bear, and Bear Creek.

Trend Analysis. The Kendall's test confirms there has been a significant increase in ammonia over the period of record at Bear-Evans Creek (J484), Cottage Creek (N484), upstream Evans Creek (S484), Covington Creek (C320) and at the mouth of McAleer Creek (A432). All of these sites, except McAleer Creek, are downstream of wetlands in areas that have experienced substantial development during the last ten years. Lakes and streams associated with wetlands in the Puget Sound region often have higher ammonia levels because the tannins and humic acids in the wetlands inhibit the break down of ammonia in the cycle. Increased impervious surface area in urbanized watersheds changes the hydroperiod of downstream wetlands (Schueler and Holland, 2000d). Flows are lower in summer time due to diminished groundwater recharge and higher during storm events due to greater runoff volumes. Lower flows and higher temperatures during the summertime may increase ammonia production. Flushing of nutrients, including ammonia from the wetlands during storm events may have increased as well.

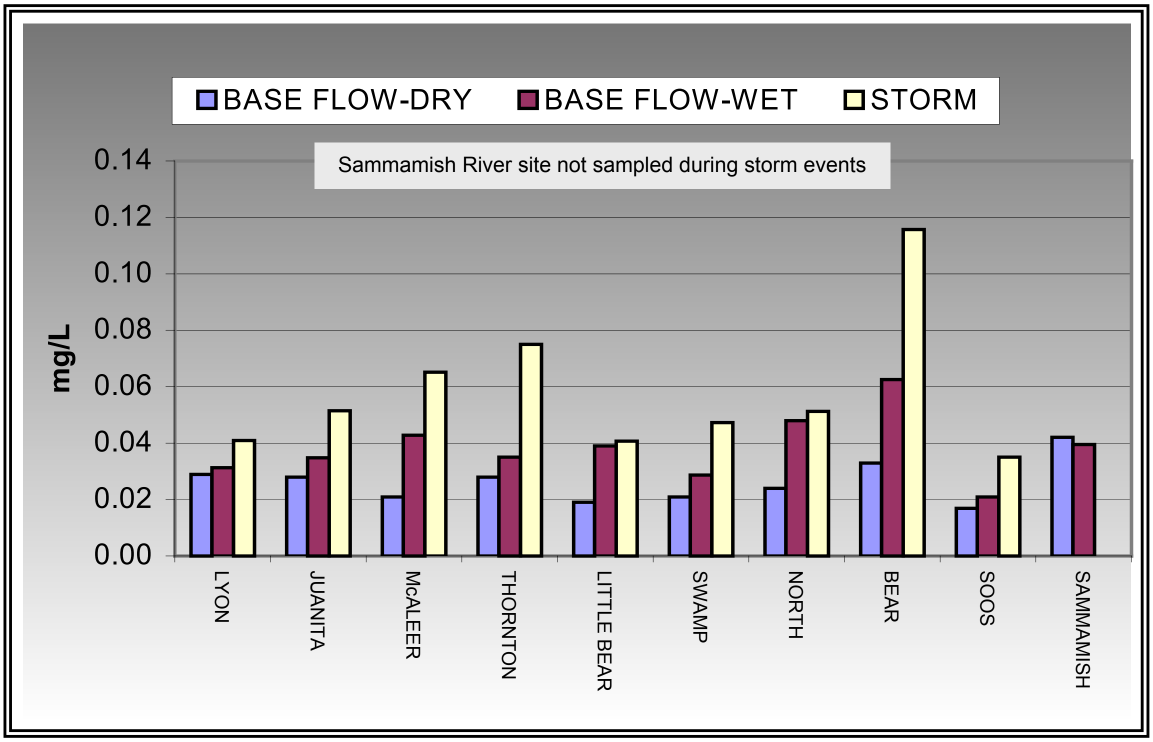

Figure 10. Average Ammonia-nitrogen for Baseline Wet and Dry Season Measurements (1979 – 1999), and Storm Event Measurements (1987 – 1999) at the mouth of each creek. Streams are ranked in order of drainage area size with Lyon Creek being the smallest (see Table 1).

Nitrate+nitrite (NO_3-NO_2)

Under natural conditions, the primary source of NO_3- in streams is terrestrial decomposition of organic materials. In soils, the regeneration of NO_3- from organic nitrogen occurs through the activities of bacteria and fungi. These organisms convert organic nitrogen forms to ammonia, and then nitrite bacteria partially oxidize ammonia (NH_4+) to nitrite (NO_2-). Under aerobic conditions, another group of bacteria converts nitrite to nitrate. In addition, some plants fix atmospheric nitrogen. Bacteria on the roots fix the nitrogen in the soil by combining it with oxygen to form nitrate (NO_3-). Alder trees (*Alnus sp*.), which are prevalent along many of the streams, are the primary source of the nitrogen-fixing bacteria in forested areas and wetlands. Nitrogen fixation by dense stands of alder can be as high as 22,500 mg/m^2/year, most of which enters the stream as leachate from direct leaf-fall or release during decomposition of foliage (Wetzel, 1975).

As land is prepared for cultivation or other uses, the trees are removed and the soils become more vulnerable to leaching and erosion. Nutrient levels in the water increase initially and then gradually decrease until the nutrients are leached from the soil, the soil is washed away or the soil is again protected by re-growth of vegetation. After land is converted to either single-family residential or agricultural use, fertilizer use generally increases. Fertilizers readily dissolve and if not utilized by plants where they are applied will be washed into the streams.

In King County, there has been a trend to squeeze more animals on smaller parcels. If land is converted to pasture and if the number of livestock exceeds the carrying capacity of the plot, additional food is brought in to sustain the animals. The livestock only retain a small portion of the nutrients and excrete the rest onto the surface of the land. Since there was insufficient vegetation to support the animals in the first place, the vegetation is insufficient to take up most of the nutrients the animals excreted; consequently, much of that material makes its way to the streams. Unless the landowner is very meticulous about replanting vegetation, maintaining optimal fertilizer application rates and managing excess manure from pastures, the nutrient levels in the adjacent streams can be expected to increase.

<u>Baseline versus Storm.</u> Storm averages show dilution of nitrate+nitrite to varying degrees depending on the level of residential development in the watersheds. Nitrate concentrations in storm averages were between 50% and 75% of the baseline averages for both wet and dry seasons in Thornton, McAleer, Lyon, and Juanita Creeks (Table 13, Figure 11). This suggests that in these streams, the source of nitrate+nitrite may be groundwater and that the nitrate concentration in the streams is diluted by surface runoff during storm events.

Table 13. Summary of Nitrate+Nitrite Concentrations in Baseline and Storm Measurements.

NO_3+NO_2 (mg/L)	Baseline (n=4,738)	Storm (n=330)
Overall Mean (all sites)	0.86	0.82
Range of Site Means	0.26 – 1.44	0.67 – 0.93
% of Total Not Meeting Criteria	Not applicable	Not applicable

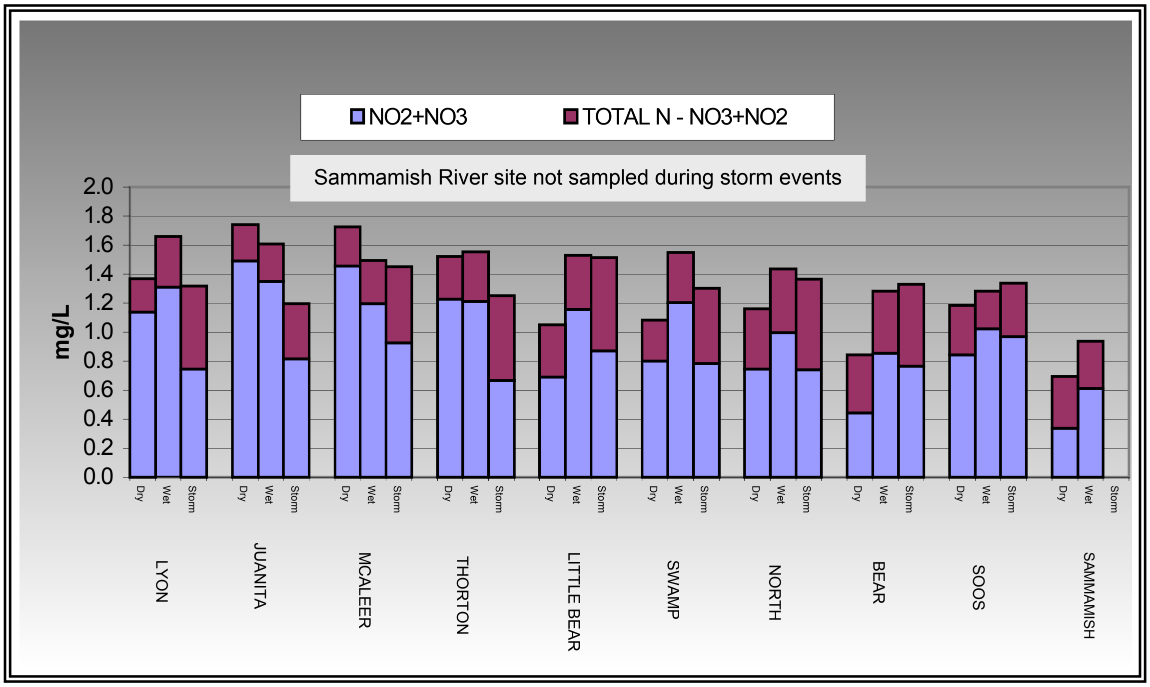

Figure 11. Average Total Nitrogen and Nitrate+nitrite for Baseline Wet and Dry Season Measurements (1979 – 1999), and Storm Event Measurements (1987 – 1999) at the mouth of each creek. Streams are ranked in order of drainage area size with Lyon Creek being the smallest (see Table 1).

Wet/Dry Seasons. Nitrate+nitrite concentrations generally were highest in the winter and gradually diminished through the growing season as plant uptake increased. The levels at some sites follow this pattern very closely - the Sammamish River sites 0450 and 0486, and on Juanita Creek (C446), for example. Higher wet season averages may also be an indication that groundwater is the source of nitrate for some of the streams. As the soils become saturated in the wet season, groundwater flows more readily into the streams transporting nitrate along with it.

Trend Analysis. The Kendall's test indicated that there has been an increasing trend in NO_3+NO_2 concentrations over the period of record at Covington (C320) and Jenkins (D320) Creeks in the Soos Creek basin. The reason for this increase was not determined.

Total Nitrogen (TN)

Total nitrogen concentrations are of interest because they enable estimation of loading to the major lakes and rivers. To calculate loading the concentration of total-N (mg/L) is multiplied by the volume of water flowing into a lake to get the overall mass of nitrogen compounds entering the lake for a given period of time. This information can be useful in determining the relative contribution of nitrogen from each source.

Baseline versus Storm. The percentage of nitrate in the total-N measurement was less in the storm (≈ 60%) than in baseline samples (≈ 75%). Ammonia-nitrogen concentrations increased during storm events (see above discussion). At some sites baseline total-N concentrations were higher than storm concentrations, while at other sites the reverse was true (Table 14, Figure 11).

Table 14. Summary of Total Nitrogen Concentrations in Baseline and Storm Measurements

Total Nitrogen (mg/L)	Baseline (n=1,626)	Storm (n=210)
Overall Mean (all sites)	1.17	1.34
Range of Site Means	0.52 – 1.71	1.20 – 1.51
% of Total Not Meeting Criteria	Not applicable	Not applicable

Wet/Dry Seasons. The total-N average concentration in the storm samples was not significantly different from either the wet season or dry season baseline averages. However, the other measured fractions of total nitrogen appear to vary in their relative concentrations on a seasonal, weather-related basis.

It is assumed that the fraction of total nitrogen that is not nitrate is either ammonia-nitrogen or some other organic form of nitrogen. Fertilizers for lawns contain nitrogen compounds, such as ammonium nitrate, that readily dissolve in water but are not adsorbed by soil particles. Consequently, these nitrogen compounds reach receiving water via both ground water and surface water flow. Ammonia-nitrogen concentrations were higher during the wet season and storm events.

When present, nitrate+nitrite ions increase the conductivity of water. There was a significant correlation between baseline conductivity and baseline total-N and nitrate+nitrite-N concentrations. In this region, elevated conductivity may indicate elevated nitrogen loading. The streams with the higher conductivity averages tend to be those that drain more urbanized basins.

Trend Analysis. Since the period of record for total nitrogen covers only seven years, trends are not discernible.

Phosphorus (Ortho-Phosphorus, Total Phosphorus)

In most fresh water systems, phosphorus is less abundant relative to the concentration of nitrogen and the nutrient demands of plants. Phosphorus is therefore termed the "limiting nutrient." While plants need both nitrogen and phosphorus, it is the availability of phosphorus that limits plant growth. As phosphorus supplies run low, plant growth slows or stops. Likewise, when supplies increase, algae thrive. This increase in growth can result in nuisance algal blooms. Therefore, phosphorus is the nutrient of most concern with regards to eutrophication of lakes and often the focus of lake management plans.

Phosphorus is found naturally in soil, plants, and animal tissue. However, the bedrock in this region is relatively low in phosphorus. Elevated amounts of this nutrient are nearly always linked to human activities such as poor gardening and animal management practices, and failing septic systems. Phosphorus in animal feces is also a problem when waterfowl populations become large or when large animals such as horses and cattle have free range near a stream or lake. Unlike nitrogen, most of the phosphorus reaches the receiving waters during storm events and much of it seems to be associated with particulate material. Once phosphorus enters a lake, it can be recycled via plant growth, decay, and sediment release. Two forms of phosphorus were measured in this monitoring program: total phosphorus (total-P) and ortho-Phosphorus (ortho-P) (see Figure 12).

Total Phosphorus

Total phosphorus includes all forms of the nutrient, including the phosphorus bound in plant and animal tissue, attached to soil particles, and dissolved.

Baseline versus Storm. The TP concentrations in storm samples were generally more than double the baseline values (Table 15, Figure 12).

Table 15. Summary of Total Phosphorus Concentrations in Baseline and Storm Measurements

Total Phosphorus (mg/L)	Baseline (n=4,774)	Storm (n=330)
Overall Mean (all sites)	0.060	0.147
Range of Site Means	0.026 - 0.089	0.103 – 0.170
% of Total Not Meeting Criteria	Not applicable	Not applicable

Wet/Dry Seasons. The total-P averages for both the wet and dry baseline samples were nearly equal. The exception being at Bear Creek (0484) where the dry season average of 0.092 mg/L TP was about 20% higher than the wet season average of 0.076 mg/L TP.

Trend Analysis. The Kendall's test detected significant decreasing trends at both sites on Juanita Creek (0446 and C446), at Kenmore (0450), at Swamp Creek (0470), and at North Creek (0474). (There was also a significant decrease in ortho-Phosphorus at Kenmore, Swamp Creek, and North Creek.) The total-Phosphorus levels decreased at several sites in the Bear-Evans Creek basin as well (0484 at the mouth, C484 and J484 on the mainstem, Cottage Creek-484 and the mouth of Evans Creek-484). Although the baseline water quality sampling procedure did not specifically target Best Management Practices (BMP) projects, it is felt that widespread education and implementation are contributing factors to these decreasing trends.

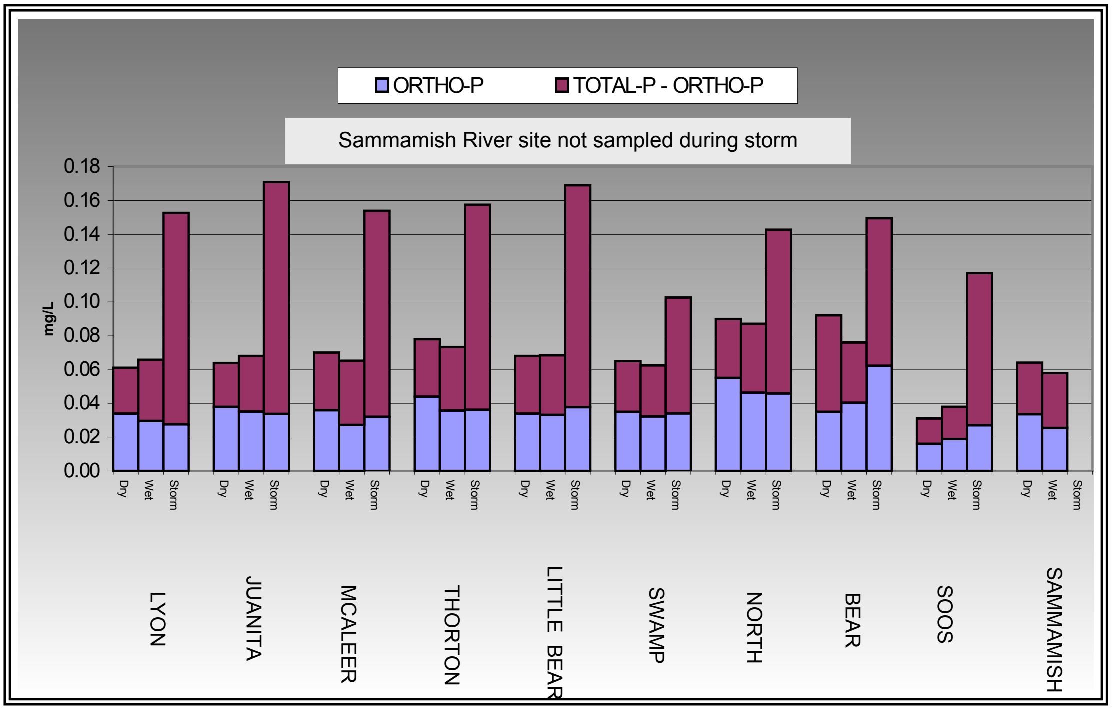

Figure 12. Average Total Phosphorus and ortho-Phosphorus for Baseline Wet and Dry Season Measurements (1979 – 1999), and Storm Event Measurements (1987 – 1999) at the mouth of each creek. Streams are ranked in order of drainage area size with Lyon Creek being the smallest (see Table 1).

Ortho-Phosphorus

Ortho-P is a dissolved form of phosphorus, which is readily available for utilization by plants. Phosphorus binds readily with iron in soil particles and sediments. When oxygen concentrations become low, the iron-phosphorus bond is broken and the dissolved form of phosphorus is released into the water column. Synthetic detergents or fertilizers are also a source of dissolved phosphorus.

Baseline versus Storm. Storm ortho-P concentrations were similar to baseline concentrations except at Bear Creek (0484) where the storm average was nearly twice the baseline (Table 16, Figure 12).

Table 16. Summary of Ortho- Phosphorus Concentrations in Baseline and Storm Measurements

Ortho-Phosphorus (mg/L)	Baseline (n=4,654)	Storm (n=330)
Overall Mean (all sites)	0.030	0.038
Range of Site Means	0.011 - 0.051	0.028 – 0.062
% of Total Not Meeting Criteria	Not applicable	Not applicable

Wet/Dry Seasons. The average wet and dry baseline ortho-P concentrations were similar (within 0.005 mg/L).

Trend Analysis. Concentrations of ortho-P occurred April through August and then declined through the fall and winter. Over the period of record there were decreasing trends detected at Kenmore on the Sammamish River (0450), Swamp (0470), and North (0474) Creeks. These sites also had decreasing trends in total phosphorus (see above discussion).

Bacteria (Fecal Coliform, Enterococcus)

Criteria

The surface Water Quality Standards for the State of Washington (WAC 173-201B) contain bacteria criteria designed to reduce the chance of people becoming ill from eating shellfish, swimming, or wading in the waters of the state. The current criterion for bacterial pollution is based on using fecal coliform as an indicator of public health risk to swimmers. The Washington fecal coliform standard for class AA waters is the geometric mean shall not exceed 50 organisms/100 ml and that not more than 10% of the samples shall exceed 100 organisms/100 ml (State of Washington, 1992). Violations of the fecal coliform bacteria standard is the primary cause for reporting impaired waters in King County's submittal to the Washington Department of Ecology 303(d) (impaired waters) list. This standard is currently under review by the Washington State Department of Ecology.

In 1986, the USEPA recommended that states move away from using fecal coliform bacteria as an indicator of human contamination, and use either *E. coli* or enterococci for their bacterial indicator criteria. The recommendation for using Enterococcus was made because it better mimics the survivability of water borne pathogens that are difficult to control through disinfection. The various bacterial indicators that are currently used are affected differently in the aquatic environment and by disinfection processes (Cabelli, 1978).

While specific indicator bacteria may not be pathogenic to humans, their presence indicates the potential presence of pathogenic bacteria and viruses that occur in conjunction with the indicator bacteria. Most fecal coliform bacteria do not cause disease, but co-exist in the intestines with disease-carrying pathogens that pose a public health risk. The higher the fecal bacteria counts, the higher the probability of pathogenic bacteria pollution.

In order of specificity to the feces of warm-blooded animals, *E. coli* is the most specific, closely followed by Enterococcus, and then weakly followed by fecal coliform. *E. Coli* is essentially entirely fecal specific, although it can occur in specific industrial wastewater lagoons (Hicks, 2000). Enterococci are not specific to fecal sources, and can come from both insects and plants. However, the majority of enterococci measured in natural waters are contributed by warm-blooded animals (Hicks, 2000). Enterococci are found to be present in much higher numbers in humans (38-8%) than in non-human wastes (0-25%) (Rutkowski and Sjogren, 1987).

While their presence indicates fecal contamination, none of these bacterial indicators differentiate between human and other animals. Molecular identification techniques that typed *E. coli* RNA identified ducks, geese, domestic dogs and cats, raccoons as sources of bacteria in Pipers Creek, Juanita Creek, and at the swimming beach at Juanita Park (Samadpour, unpublished data 1998). Likewise, a molecular identification study on Little Soos Creek found cows, and dogs to be the greatest contributors overall to stream fecal coliform contamination (Samadpour and Chechowitz, 1985). This diminishes the efficacy of using fecal bacteria as indicators of human sewage pollution, but testing for them remains useful in evaluating overall non-point source pollution. The direct analysis of pathogens is technically difficult, elusive, and expensive.

King County currently monitors by monthly grab sampling a combination of fecal coliform, *E. coli* (swimming beaches only), and Enterococcus bacteria levels as indicators of sewage pollution in lakes and streams. The original fecal coliform criterion was based on disease studies carried out at beaches in the 1940’s and 1950’s. Based on the results of these studies, a total coliform criterion of 2300/100 ml was promulgated for swimming. This standard was modified in the 1960’s to fecal coliform criteria, based on an estimate that ~18% of the coliforms are typically fecal coliforms. It was assumed that there would be a detectable health risk when fecal coliform counts were >400/100 ml, therefore the standard was set at 200/100 ml to provide a margin of safety. Statistically significant increases in gastrointestinal disease are not typically observed at concentrations of fecal coliform below 100/100 ml, which means that low counts of fecal coliform give some assurance of low disease risk conditions. While the fecal coliform standard has performed poorly in detecting rates of gastrointestinal illness, fecal coliform is useful as an indicator for skin, eye, and respiratory illnesses.

A problem with the fecal coliform tests is that they also enumerate the non-fecal *Klebsiellae* bacteria. These bacteria are non-pathogenic, and their enumeration can result in overstating health risks, particularly in bathing waters with a high wood waste component. In contrast, *E. coli* (which is a sub-group of the fecal coliforms) is highly specific to fecal sources and does not enumerate *Klebsiellae* species.

Bather studies have shown *E. coli* to be an effective indicator of the sanitation of freshwaters and sometimes for marine waters. The USEPA discourages the use of *E. coli* as a marine indicator since it is more easily eliminated from wastewater through disinfection than many of the pathogens of concern in sewage effluent. This is a bigger issue in using *E. coli* to evaluate the efficacy of sewage treatment than it is in non-point monitoring, as there is no disinfection associated with accidental sewage spills, overflows, or non-point pollution. Therefore it is inappropriate to use the same indicator for both swimmability in freshwater and disinfection in marine waters.

Enterococcus bacteria are non-pathogenic subgroup of fecal *Streptococcus* and are often measured as an indicator of the presence of human fecal material. Enterococcus is considered to be an excellent indicator of the sanitary quality of both fresh and marine waters because they survive in the environment better than fecal coliform or *E. coli*, as well as many enteroviruses and many of the pathogens of greatest concern. Epidemiological studies have determined a correlation between Enterococcus concentrations in water and increased probabilities of illness in swimmers, although Enterococcus are not usually the cause of illness (Dufour, 1984). There is no current state standard for Enterococcus in fresh waters, but the proposed criteria would be set at 33/100 ml as a geometric mean with no more than 10% of samples exceeding 61/100 ml (Hicks, 2000).

<u>Baseline versus Storm - *Fecal coliform*</u>. - Not one of the streams assessed in this report met the fecal coliform standard for either the baseline or storm event monitoring (Appendix V). Only one site, Marymoor Park on the Sammamish River (0486) which monitors outflow from Lake Sammamish, met the geometric mean provision of the standard in the baseline sampling. However, since 13% of the baseline samples exceeded 100 organisms/100 ml, this site did not

meet both components of the standard. Thornton Creek had the highest geometric mean for both baseline and storm sampling (Table 17, Figure 13).

Table 17. Summary of Bacteria Counts in Baseline and Storm Measurements

Bacteria (organisms/100 ml)	Baseline		Storm	
	Fecal coliform n = 4,815	Enterococcus n = 2,649	Fecal coliform n = 330	Enterococcus n = 325
Overall Geometric Mean (all sites)	218	130	1,186	1,442
Range of Site Geometric Means	29 - 639	15 - 353	685 – 3,065	836 – 3,292

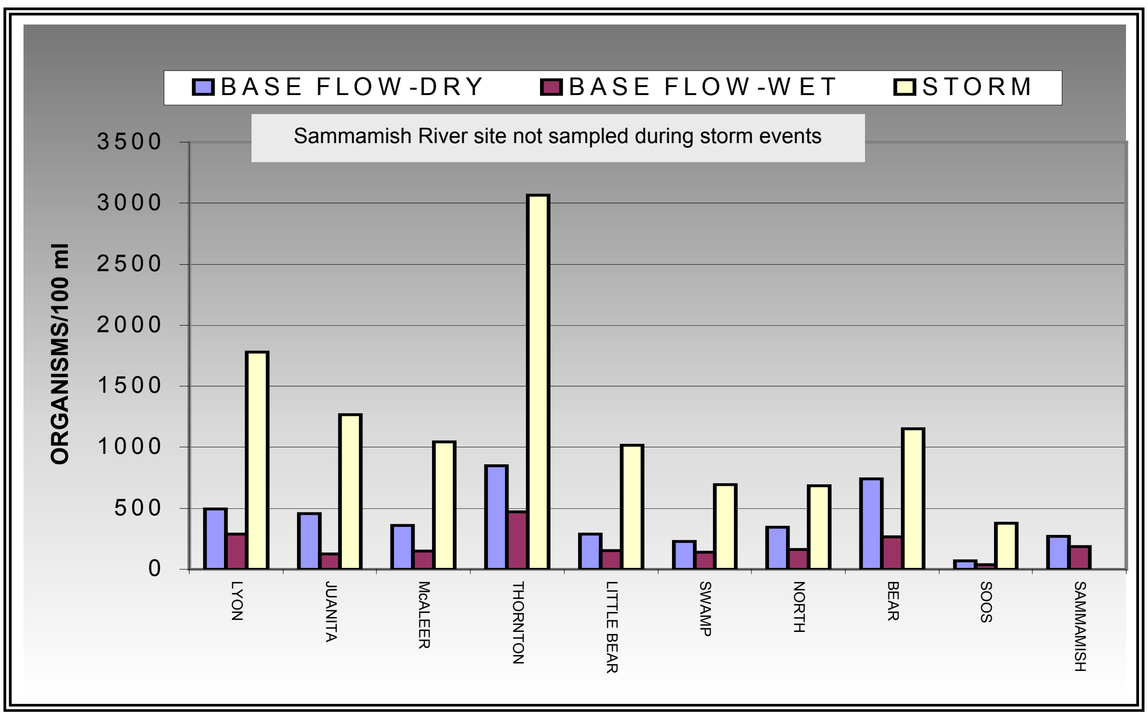

Figure 13. Geometric Means of Fecal Coliform Bacteria Counts for Baseline Wet and Dry Season Measurements (1979 – 1999), and Storm Event Measurements (1987 – 1999) at the mouth of each creek. Streams are ranked in order of drainage area size with Lyon Creek being the smallest (see Table 1).

Baseline versus Storm - Enterococcus. - The baseline Enterococcus geometric means were at or below 33 organisms/100 ml at only one of the twenty baseline sites evaluated in this report- A320 on Covington Creek in the Soos Creek Basin (Appendix V). Only nine of the 325 storm samples were below the 33 organisms/100 ml. Thornton Creek had the highest geometric mean of Enterococcus in both the baseline and storm sample sets (Table 17, Figure 14).

Bacteria levels increased in storm conditions. Enterococcus levels increased twelve-fold and the fecal coliform levels were six times as high during storms. Some of the highest counts and most radical increases in bacterial counts occurred during the first storm of the rainy season, which typically occurs in October after the prolonged low rainfall summer period. This pattern is often referred to as the “first flush effect” where pollutants that accumulate during the dry period are washed into the streams with the first major rain event of the year. In agricultural areas, one would expect that manure washed from pastures during storms would result in elevating bacteria levels. However, the highest levels and greatest increases were found in the most urbanized basins where there is no livestock.

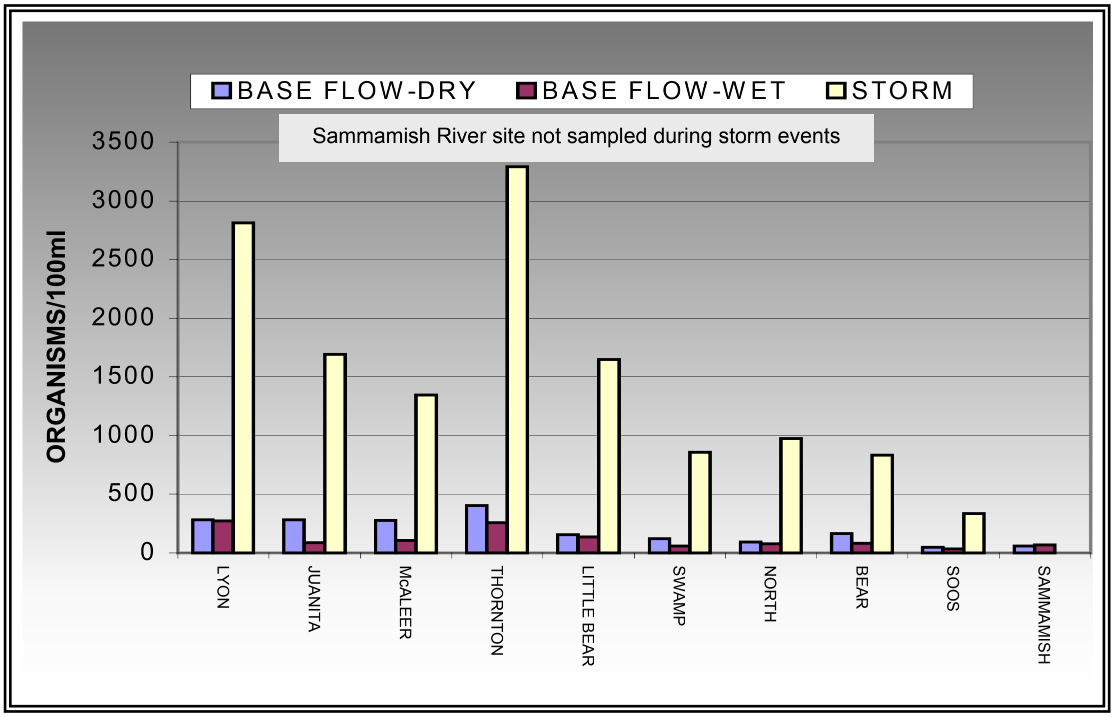

Figure 14. Geometric Means of Enterococcus Bacteria Counts for Baseline Wet and Dry Season Measurements (1979 – 1999), and Storm Event Measurements (1987 – 1999) at the mouth of each creek. Streams are ranked in order of drainage area size with Lyon Creek being the smallest (see Table 1).

Wet/Dry Seasons. *Fecal coliform and Enterococcus*. Even though storm samples had higher concentrations than either wet or dry season baseflows, the baseflow bacteria geometric mean concentrations for fecal coliform bacteria were higher in the dry season than the wet season at every site. The magnitude of the higher geomeans ranged from 62 percent higher at the mouth of Swamp Creek (0470) to 350 percent higher at Juanita Creek. Enterococcus geomeans were substantially (greater than 60 percent) higher in the dry season than the wet season at Juanita, McAleer, Thornton, Swamp, and Bear creeks. At the other sites, the wet and dry season Enterococcus geomeans were not significantly different. This pattern may represent a flushing of the streams during storm events, that potentially removes some of the residual bacteria in the streams.

During the dry season, less dilution from lower stream flows and slower water movement probably contributes to the higher bacteria counts. Conversely, increased photolysis of the bacteria during the sunnier low flow season decreases the period of time viable bacteria will persist in stream or lake water. If any of the bacteria sources are chronic, such as leaking sewer pipes, cross connections, or failing septic systems, elevated bacteria counts should be seen regularly throughout the low flow periods. Thornton, McAleer, Lyon, and to a lesser extent Little Bear and Juanita Creeks exhibit a pattern of chronically high bacteria (both fecal coliform and Enterococcus) which indicates potential persistent sources of bacterial pollution.

Bacteria sources, such as large populations of waterfowl, are more transient and depend on the distribution of the wildlife in the watershed. In most of the streams sampled, there is limited waterfowl habitat compared to wetlands or lakes. An exception is Meadowbrook Pond in Thornton Creek, which attracts waterfowl to the restored habitat created in the park. The typical design of lakeshore parks, and waterfront residences with large expanses of non-native turf-lawn adjacent to open water, are particularly attractive to waterfowl. In recent years large congregations of introduced non-migratory waterfowl have contributed to the bacterial pollution of these areas.

Trend Analysis. *Fecal coliform and* Enterococcus - *Enterococccus* concentrations were too variable to detect trends.

Fecal coliform - The Kendall's test results from twenty-two sites indicated significant trends at sixteen sites. In most cases, the trends showed a decrease in bacteria levels over the sampling period. The most dramatic of these decreases was at North Creek (0474), Little Soos Creek (G320), and at the mouth of Bear Creek (0484). Changes in land use activities from hobby and commercial farms and reduction of livestock related activities at all three of these sites are a probable cause for the decreases in bacteria. Unfortunately, no decreasing trend has occurred in the urbanized streams in this study, which have exhibited high levels of bacterial pollution for several years, and continue to do so.

While few of the streams meet either the current or proposed WDOE bacteria standards, Thornton, McAleer, Lyon, and Juanita creeks have both chronically high fecal coliform and Enterococcus bacteria counts. These stream basins are heavily urbanized, with little or no livestock remaining in the basins. These streams also have the older urban development and infrastructure. Only Little Bear Creek, which primarily lies outside the Urban Growth Boundary, remains semi-rural, and has contributions of bacteria probably related to livestock, has exhibited a decreasing trend.

It is difficult to reconcile the decrease in bacteria counts in the formerly rural watersheds to urbanization of these watersheds since the most urbanized watershed in this study had the most chronic bacterial pollution. The decreasing trends in Little Soos and Little Bear Creek may represent a decrease in livestock and hobby farms in the watersheds, or could be a result of the relative newness of development. Recent developments have newer infrastructure, built to higher water quality standards with more BMPs. Older urban areas are more likely to exhibit failing or degraded infrastructure and a higher likelihood of leaking sewer lines or failing septic systems.

There are differences in flow and bacteria concentration patterns between the smaller urban streams (Thornton, McAleer, Lyon, and Juanita) and the streams with higher flow (Swamp, North, Little Bear, Soos, and Sammamish Slough) (Figures 15a-i. The level of urbanization and the concomitant impervious surface and in-pipe storm drainage in the Thornton, McAleer, and Lyons watershed relative to the watershed area may also contribute to the high bacteria counts in these streams. There are plenty of non-point bacteria sources and less dilution water. Swamp, North and Little Bear have lower density development and higher flows, which may contribute to the lower bacteria concentrations in these streams.

Figures 15a through 15i. Bacteria counts versus stream flows at the mouth of each creek.

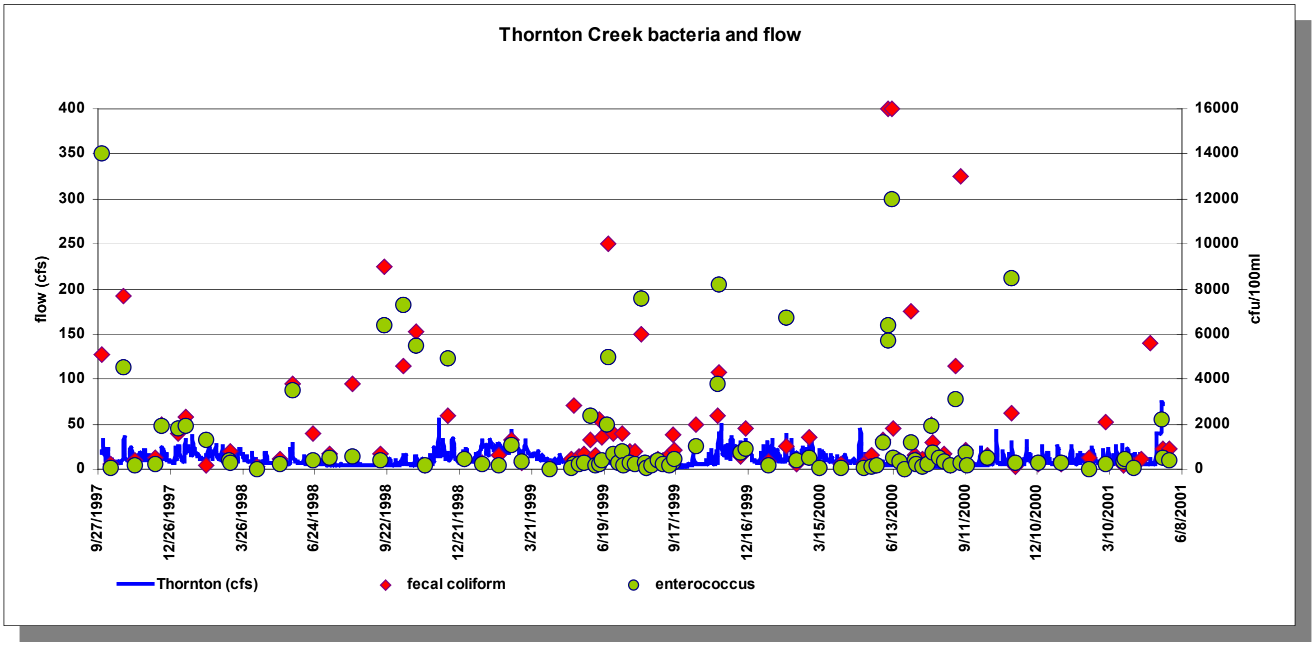

Figure 15a. Thornton Creek bacteria and flow

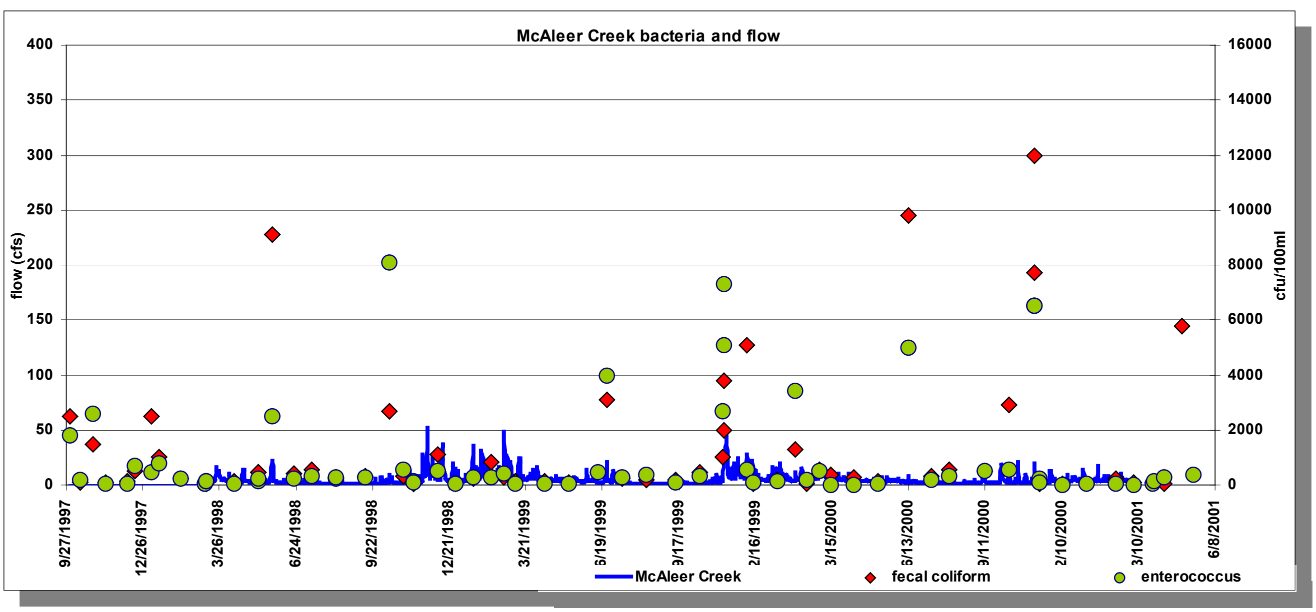

Figure 15b. McAleer Creek bacteria and flow

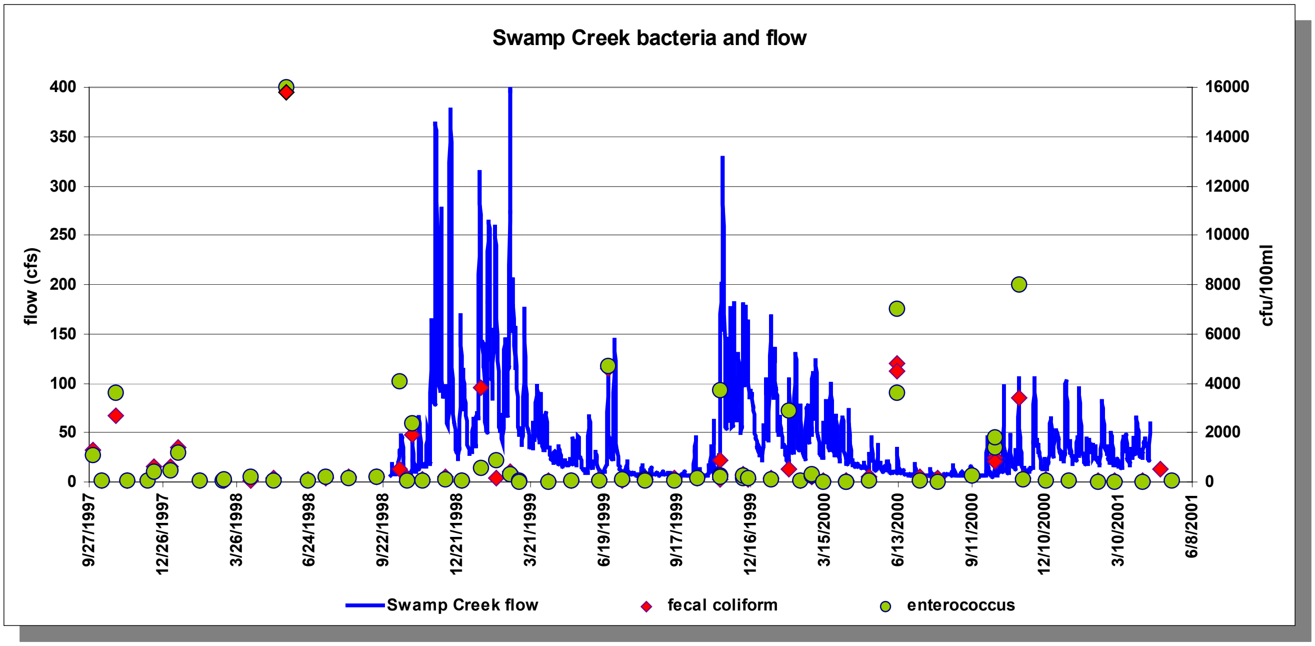

Figure 15c. Swamp Creek bacteria and flow

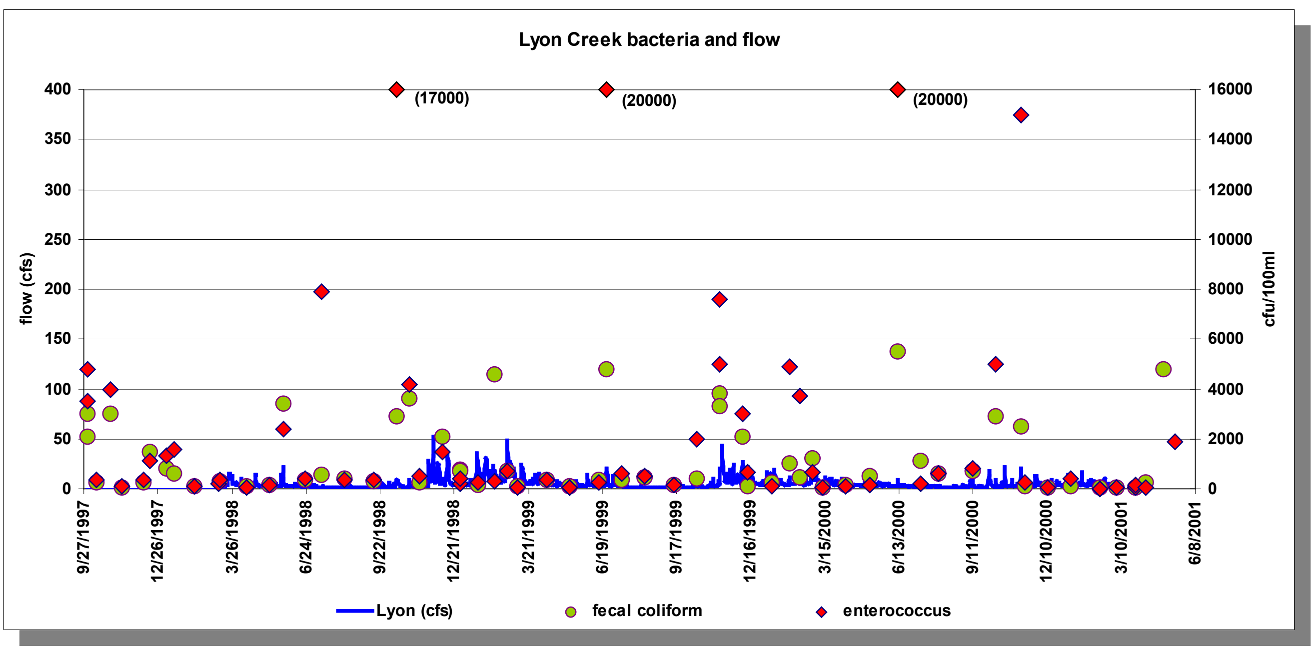

Figure 15d Lyon Creek bacteria and flow

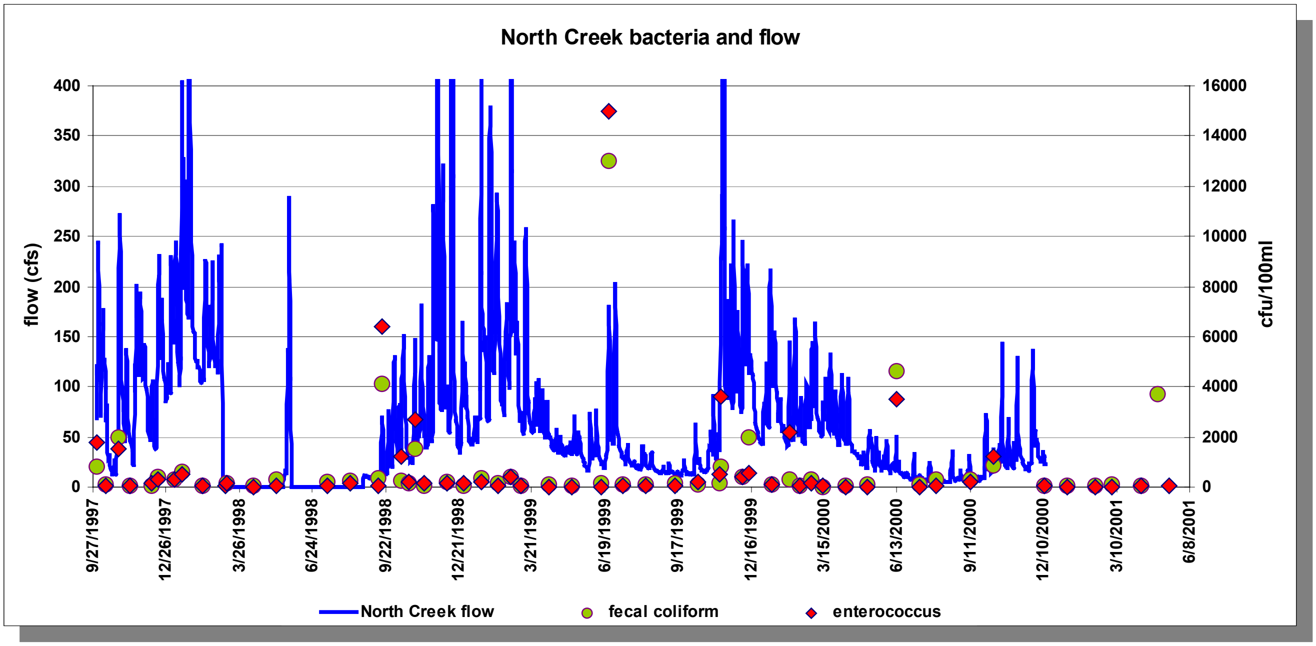

Figure 15e. North Creek bacteria and flow

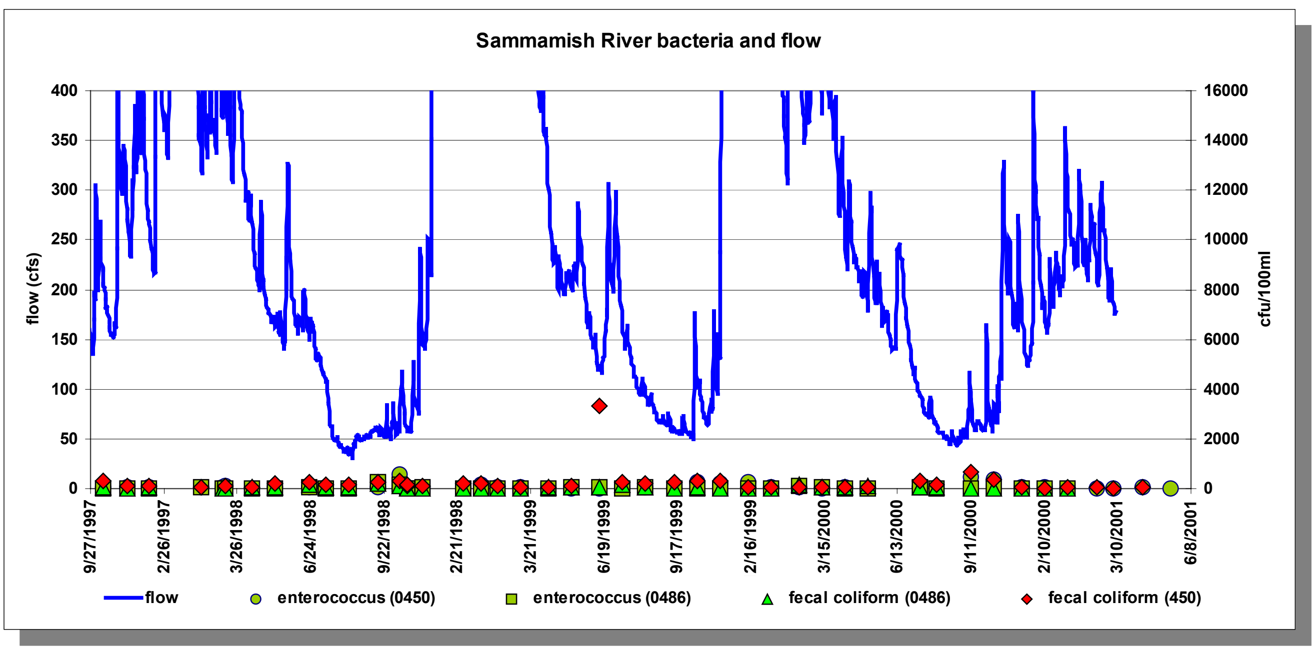

Figure 15f. Sammamish River bacteria and flow

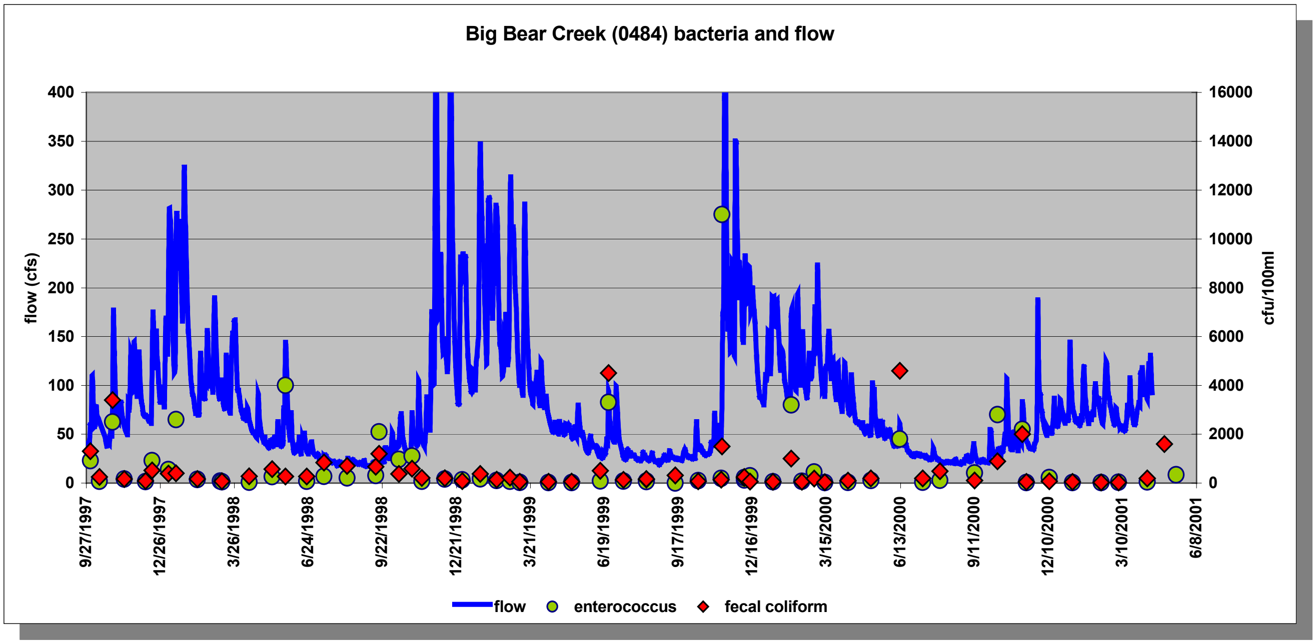

Figure 15g. Big Bear Creek bacteria and flow

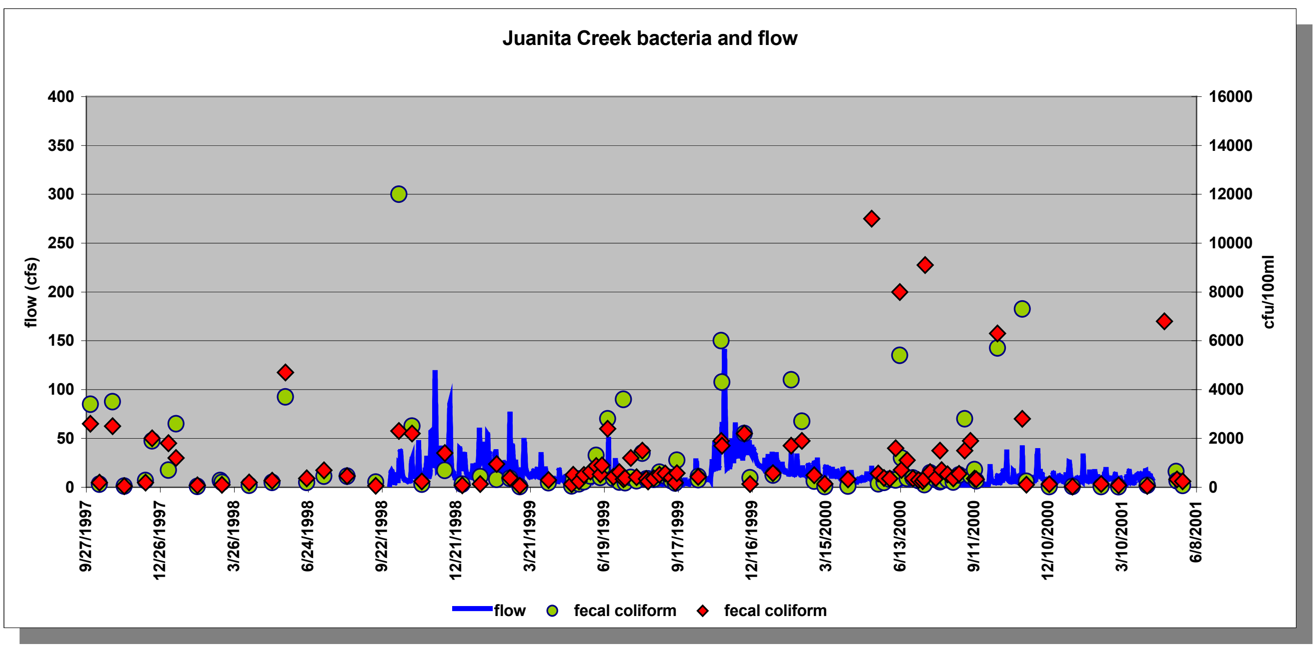

Figure 15h. Juanita Creek bacteria and flow

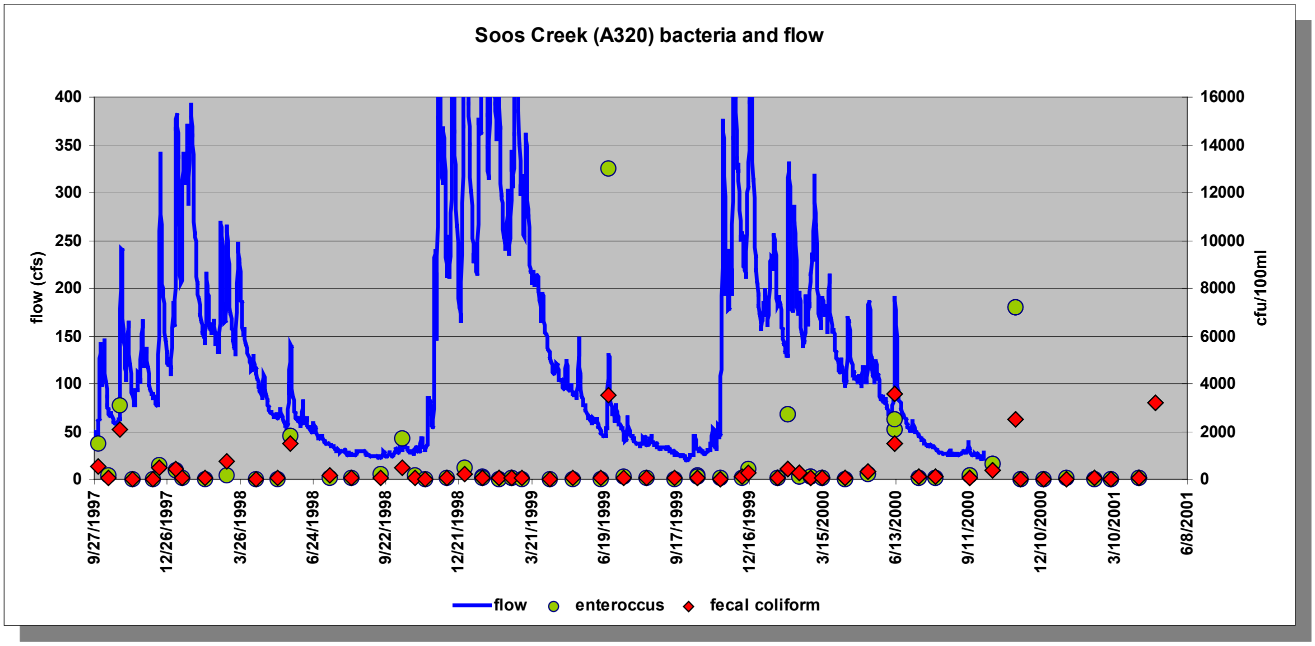

Figure 15i. Soos Creek bacteria and flow

In August 1998, the United States Geologic Survey (USGS) sampled several streams and rivers in the Puget Sound Basin as part of the National Water Quality Assessment Program (NAWQA) looking at multiple indicators (bacterial, viral, chemical) of sewage pollution. Streams sampled in the one week independent study included Thornton, Lyon, and Juanita, as well as Longfellow in West Seattle. The USGS documented high densities of *E. coli* and the presence of coliphages in water samples from Thornton Creek. Sampling occurred during baseflow conditions with no storms occurring for 18 days prior to sampling (Embrey, 2001).

Thornton Creek, sampled as part of the King County freshwater monitoring program, has chronically exceeded the fecal coliform standard and the proposed Enterococcus standard. Impacts from sewage pollution were clearly indicated on the basis of chemical indicators, and Thornton Creek topped the list of all sites sampled during the USGS study. This implicates humans, at least in part, as sources of fecal bacteria and viruses. The south fork of Thornton Creek and Longfellow Creek (not presented in this report, but routinely sampled as part of the County freshwater monitoring program) are also implicated as having human sources of bacterial pollution. These findings were based on identification of Group II serotype of the F+RNA coliphages in samples from these streams (Embrey, 2001). Some wastewater chemicals were also detected in the samples from Juanita Creek; and humans cannot be excluded as sources in this stream solely on the basis of serotyping.

In the King County DNR source control study begun in April 2001, Meadowbrook Pond on Thornton Creek had high bacteria counts (Figures 16a-d). This pond has resident beavers and attracts a number of waterfowl, which are probably the major sources of bacteria along this stretch of stream. Upstream, extremely high bacteria counts (40,000 cfu/100 ml) and obvious septic conditions occurred at the retention pond that discharges into Victory Creek in Victory Creek Park. This pond has been drained and the discharge swale posted by the Public Health Department as a health risk.

Figures 16a – 16d. Fecal coliform bacteria concentrations measured in Thornton Creek during a four-day source control survey.

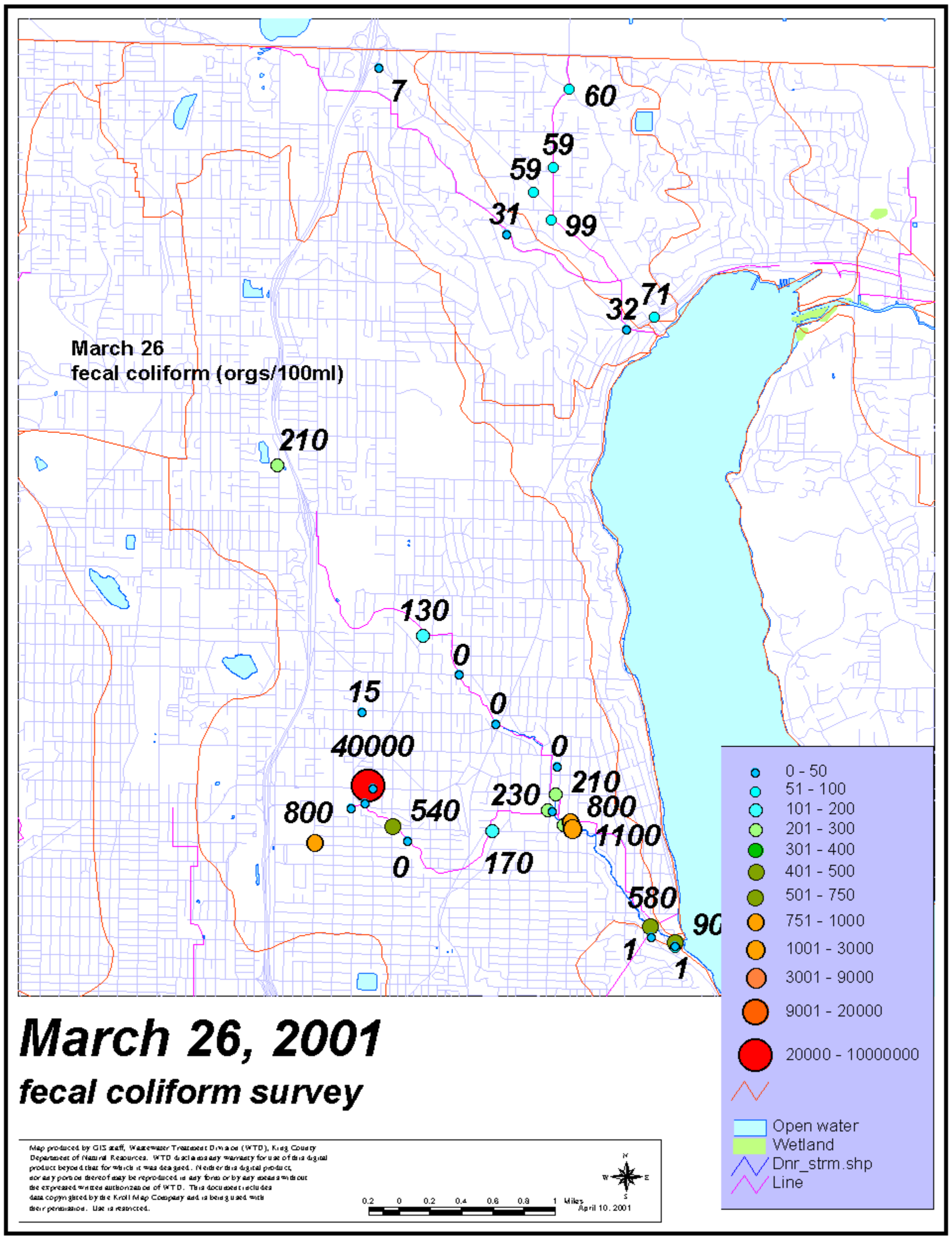

Figure 16a. March 26, 2001: Fecal coliform bacteria concentrations measured in Thornton Creek

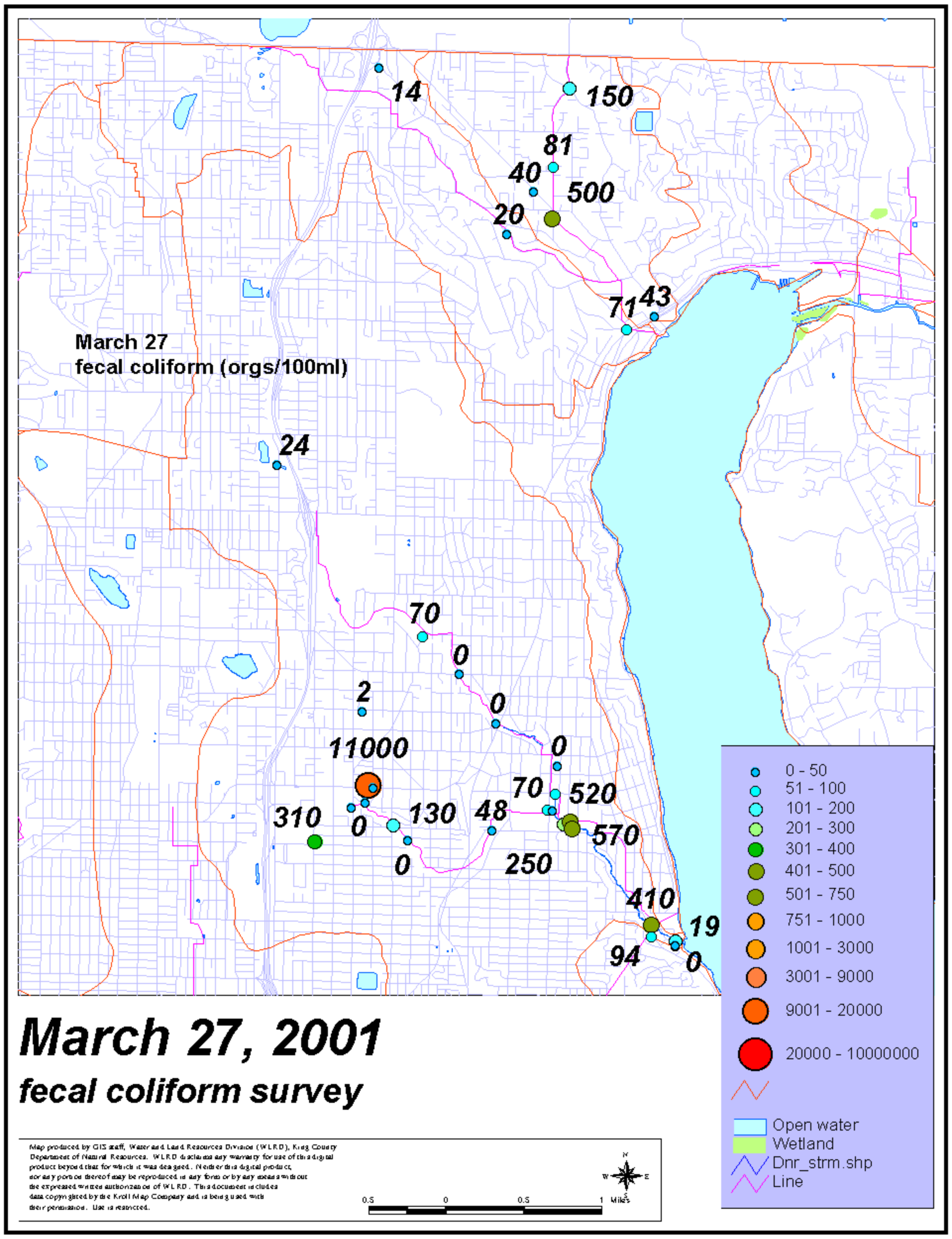

Figure 16b. March 27, 2001: Fecal coliform bacteria concentrations measured in Thornton Creek

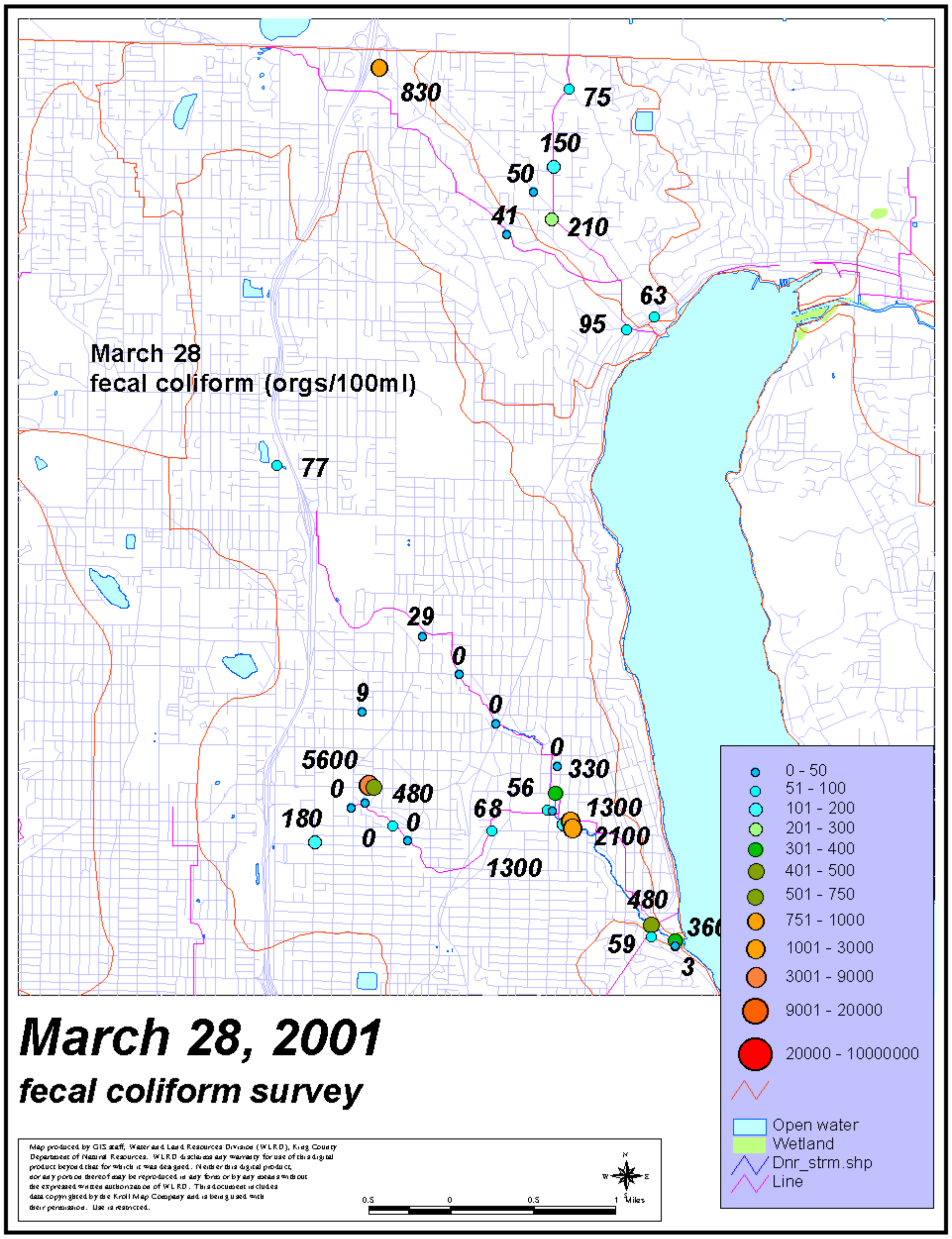

Figure 16c. March 28, 2001: Fecal coliform bacteria concentrations measured in Thornton Creek

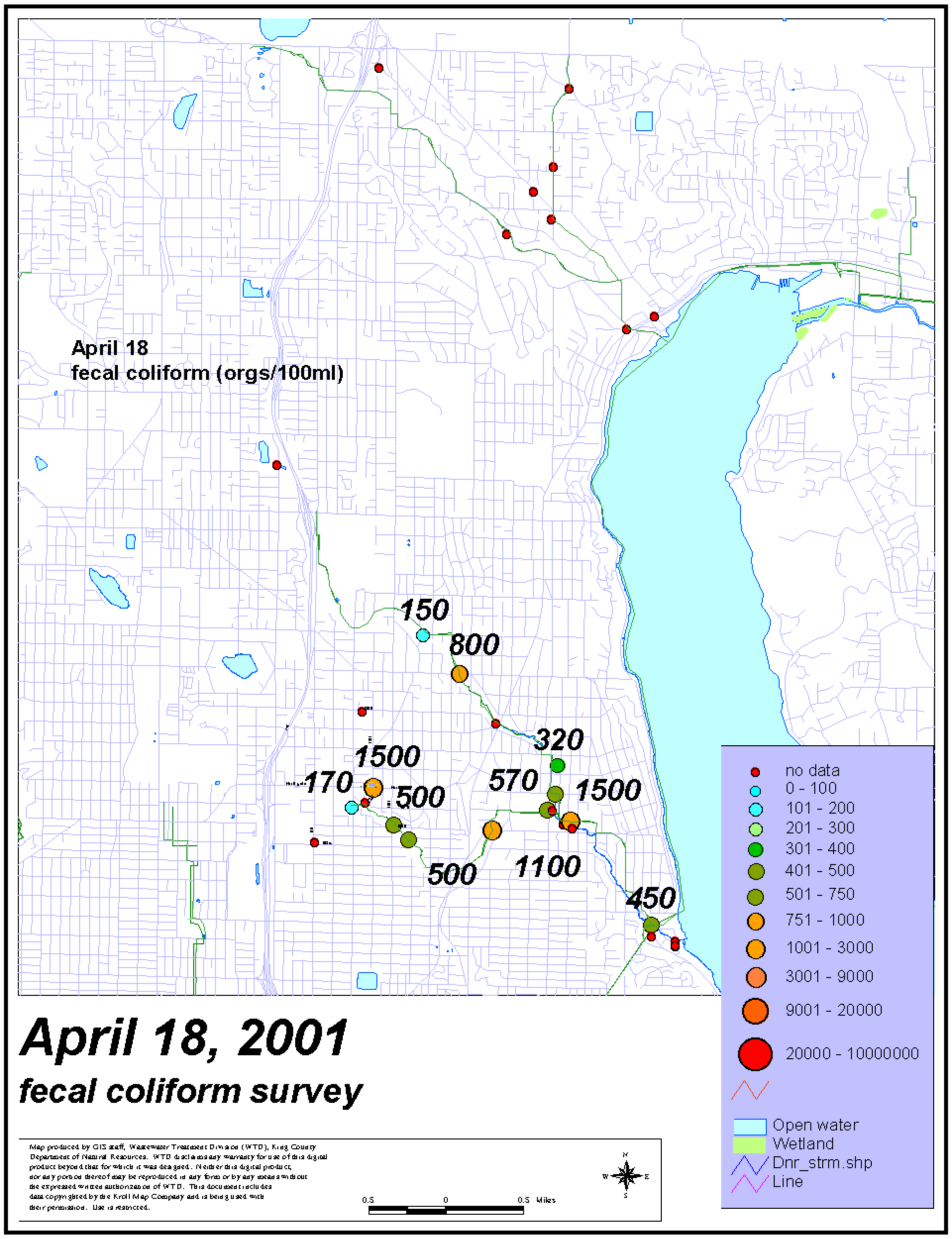

Figure 16d. April 18, 2001: Fecal coliform bacteria concentrations measured in Thornton Creek

Subsequent sampling of both Enterococcus and fecal coliform bacteria in Thornton Creek remain significantly above standards (Appendix V). While draining the retention pond had obvious water quality and public health benefits, it is also obvious from the subsequent data that several bacteria sources are still active in this basin and Thornton Creek will continue to fail bacteria criteria. Additionally, since the USGS study occurred after 18 days with no rainfall (Embrey 2001); the retention pond was not likely overflowing during the USGS sampling.

McAleer and Lyon Creeks also fail the bacteria standards on a regular basis. However, during the spring 2001 samples from both of these streams had low bacteria counts (Appendix V). Unfortunately, subsequent sampling of bacteria in both of these streams was over standards for both fecal coliform and Enterococcus, and the source remains unidentified.

Chronically high bacterial counts in these urban streams poses a public health risk. Both fecal coliform and Enterococcus counts are frequently above the levels at which increases in gastrointestinal illness and rashes related to water contact are reported to increase. Swimming and water contact are prevalent near the confluences of these streams, in the parks and play fields adjacent to the streams, and there is substantial water contact in the streams themselves. Thornton Creek empties into Lake Washington in Mathews Beach Park immediately adjacent to a major public swimming beach. McAleer and Lyon creeks discharge into the lake adjacent to a community beach. Bacteria collected in these streams are being analyzed at the University of Washington using RNA typing, in an attempt to identify the sources of the chronically high bacteria in these streams.

In order to control the bacteria pollution that occurs in these streams, the specific sources need to be identified. Source tracing entails identifying the species that contribute the bacteria, and the specific location at which the bacteria enter the streams. Many of these sources are ephemeral and transient, which also makes them difficult to locate. Increased geographic and temporal sampling is necessary to pinpoint and then control these pollution sources.

Storm/Wet Season Comparison to Baseline

The sites at the mouths of the streams were sampled up to six times per year during storm events from 1987 to the present. Since most of the storms sampled occurred during the fall and winter months (October through March), only baseline data from those months were used for comparison to the storm data. Average wet weather baseline data were combined for all sites and compared with the combined average stormwater data to determine how each parameter reacts during storm events. Comparison values illustrated in Figure 17 were calculated by dividing the storm average by wet season baseline average. A value >1 indicates that concentrations are higher during storms; values <1 indicate that storm concentrations are less than baseline, and value = 1, indicates the parameter is not impacted by storm events.

Most parameters increased during storm events from wet season baseline levels. Bacterial concentrations increase substantially during storm events. As expected, flows were almost double, and there was almost a fourfold increase in total suspended solids, and a threefold increase in turbidity in the storm sample averages. Phosphorus concentrations were also greater, particularly total-P which is easily bound to soil particles.

Of the nitrogen forms, only ammonia-nitrogen was greater in the storm averages than wet weather baseline samples. Total-N and nitrate+nitrite-N both were less in storm samples. Sources of ammonia include stagnant water from wetlands or storm drains as well as fertilizers such as manure and ammonium sulfate. Groundwater contributes most of the nitrate found in the streams and apparently storm runoff dilutes the concentration.

Rainwater has few ions and therefore typically has low conductivity. Unless there are soluble salts on the surface that get washed off during a storm event, stormwater is not likely to have elevated conductivity.

Trace Metals

The metals analyzed as well as the analytical methods used have changed over the period of record (Table 18). Cadmium and nickel have been measured from 1976 to the present, copper, lead and zinc were added in 1979, silver and mercury in 1989, and arsenic in 1993. Initially, metals were measured in both the baseline and storm water samples. However, since baseline samples were consistently below the contemporary detection limits, metal analysis in the monthly sampling was discontinued. Since January 1998, samples have been split into filtered and unfiltered aliquots for metal determination.

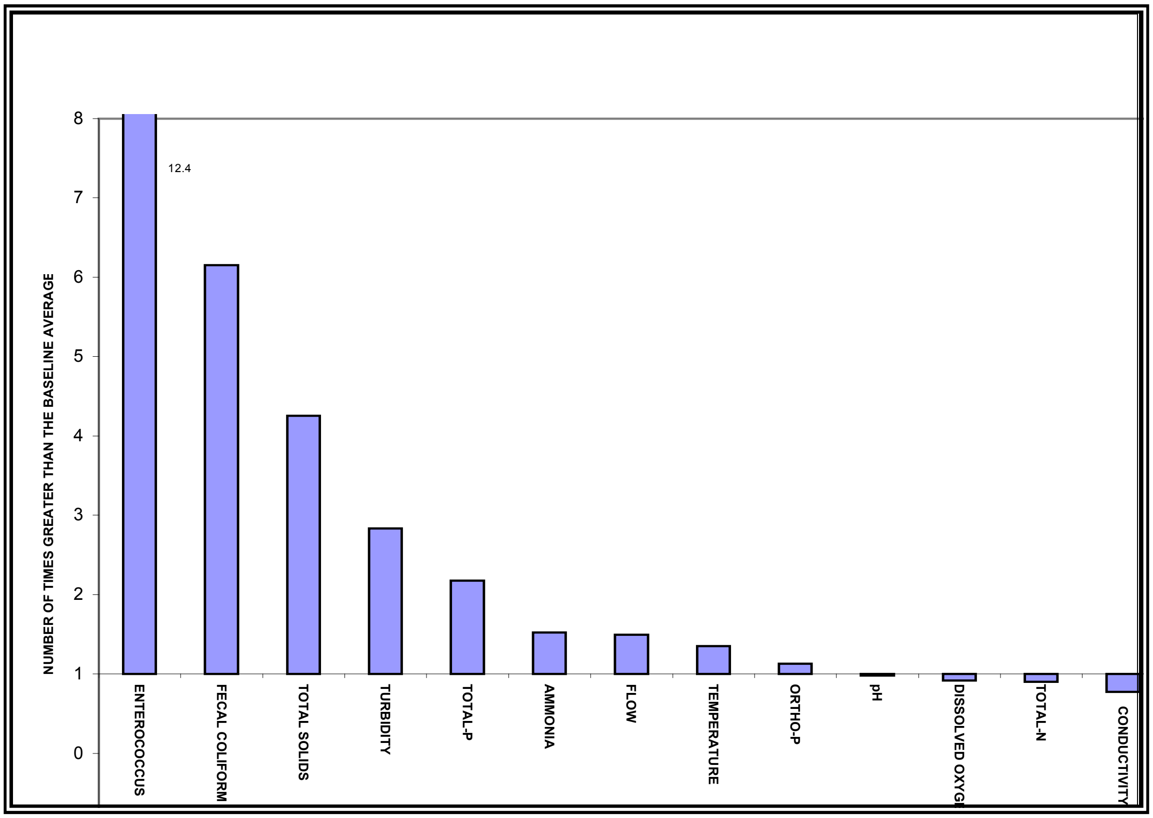

Figure 17. Average storm concentrations for various parameters divided by baseline averages for the winter months

Analytical Methods Used for Trace Metals

Three different analytical methods were used to analyze the trace metal in water samples taken over the period of record. The analytical method changed as technological improvements were made at the King County Environmental Laboratory. The detection limits for the metals analysis gradually decreased making trend analysis inappropriate because the changing limits of detection would suggest a trend where none exists. For most metals only the most recent period, since the implementation of the ICP-MS method and the lowered detection limits, can be used to determine whether the trace metal concentrations meet the State criteria.

Initially, analysis was done using an Atomic Absorption Spectrometer (AAS), then Inductively Coupled Plasma (ICP) was used, and finally, the ICP-Mass Spectrometer (ICP-MS). The AAS was used for measuring all metals but arsenic until 1993. From 1985 through 1987, a graphite furnace (GF) extraction was used in conjunction with AAS to lower the detection limits for cadmium and lead. Even with the lower detection limits, the metals were rarely found in the water samples; consequently, the GF extraction was discontinued and the detection limits returned to previous.

Table 18. Period of Record and Limits of Detection for Various Trace Metals and Analytical Methods. (mg/L)

	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99
Silver														[0.003-0.004] AAS				[0.004] ICP					[0.0002 -0.0003] ICP-MS	
Arsenic																		[0.05] ICP					[0.001] ICP-MS	
Cadmium	[0.002 – 0.006] AAS									[0.0001] AAS-GF			[0.002 - 0.003] AAS					[0.002 – 0.003] ICP					[0001-0002] ICP-MS	
Copper			[0.01] AAS															[0.004 – 0.02] ICP					[.0004-.002] ICP-MS	
Mercury														[0.002] AAS				[0.0002 – 0.0006] CVAA						
Nickel	[0.006 – 0.02] AAS																	[0.02] ICP					[.0003-.0005] ICP-MS	
Lead				[0.02 – 0.04] AAS						[.001] AAS-GF		[0.02] AAS						[0.03 – 0.15] ICP					[.0005 - .02] ICP-MS	
Zinc				[0.003 – 0.009] AAS														[0.0005 – 0.002] ICP					[.0005 - .02] ICP-MS	

AAS = Atomic Absorption Spectrometer

AAS-GF = AAS with Graphite Furnace extraction

CVAA = Cold Vapor Atomic Absorption

ICP = Inductively Coupled Plasma

ICP-MS = ICP with Mass Spectrometer

In 1993, the Inductively Coupled Plasma (ICP) method was initiated. The ICP allowed for the analysis of several metals at once, rather than one at a time as with the AAS method. While this method was faster to use, the detection limits were different for cadmium, lead, nickel and silver, making trend analysis difficult, if not impossible.

Use of the Inductively Coupled Plasma - Mass Spectrometer (ICP-MS) method began in January 1998 resulting in lowering of the detection limits and increases in the numbers of measurable levels of several metals. The numbers of measurable copper levels went from 23% with AAS to 88% using the ICP-MS, lead measurements from 23% to 71%, nickel from 8% to 73%, and zinc doubled from 49% to 98%. Percentages of samples with measurable levels of cadmium and silver dropped to zero from 9% and 4% respectively. While the detection limits did not drop for all metals, the metals that had lower detection limits resulted in nearly all data for these metals being suitable for determining whether a given stream is meeting state criteria (Table 19).

Hardness, Alkalinity and Metal Toxicity

In order to assess the toxic potential of the metals, data were compared to the criteria for the protection of freshwater life created by the USEPA and adopted by the Washington State Department of Ecology. Metal toxicity diminishes with hardness but hardness was not measured directly in any of the stream samples. Hardness can be calculated using the values for calcium (mg/L) and magnesium (mg/L):

$$\text{Hardness} = (2.497*\text{Ca})+(4.1189*\text{Mg}).$$

Calcium and magnesium were measured along with the trace metals in all but a few cases. Alkalinity (expressed as mg/L $CaCO_3$) is closely linked with hardness. The samples in which all three parameters were measured enabled the creation of a formula for estimating hardness based on alkalinity (Figure 18). This provided a means to apply metals criteria to samples in which only alkalinity were measured expanding the metals toxicity database threefold.

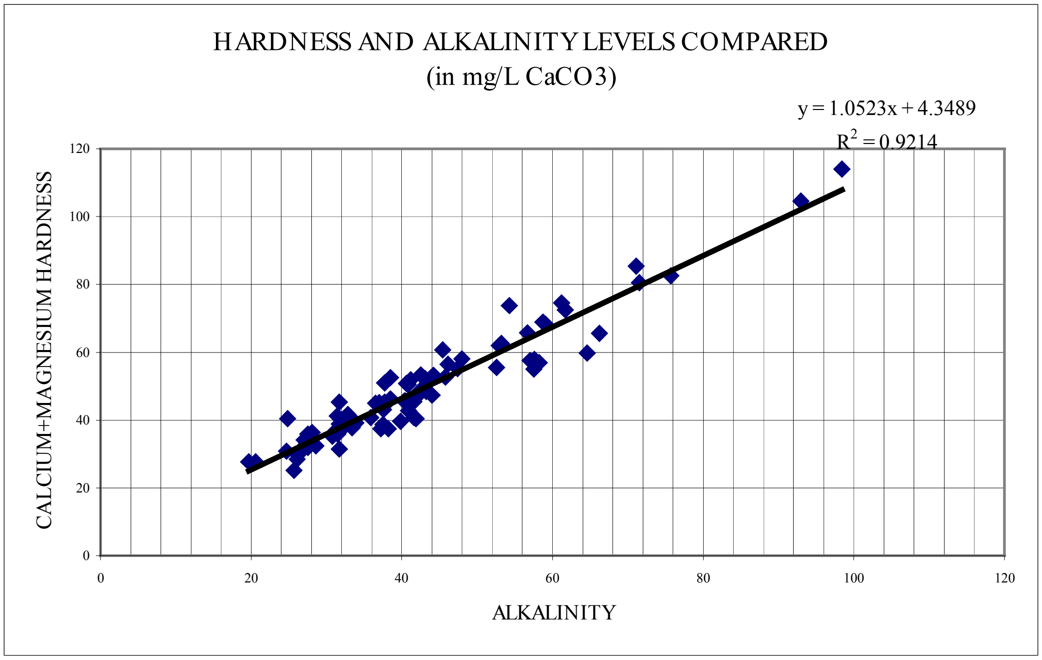

Figure 18. Comparison of alkalinity with calcium + magnesium hardness. Slope of the regression = 1.11

Hardness of each sample was estimated in one of the following three ways depending upon the available information for each stream sample:

1. Calculated from the calcium and magnesium concentrations if available.
2. Estimated by multiplying the alkalinity by 1.11 if no calcium and magnesium data is available.
3. Applied the average hardness for each site if neither alkalinity nor calcium and magnesium data is available.

Comparisons to Washington Criteria (WAC 173-201A).

From 1976 through 1998, roughly 1600 samples were analyzed for cadmium, copper, lead, nickel, and zinc. Approximately 25 percent of those samples were also analyzed for arsenic, mercury, and silver.

The data were sorted into the three main analytical methods used and the percentages of the data either meeting or exceeding the criteria are listed in Table 19. The percentages of data that had criteria below the detection limit are also shown. The analytical limits of detection for zinc, arsenic and mercury were consistently low enough that concentrations could be compared to the criteria regardless of the analytical method used. Nearly all of the samples analyzed by the ICP-MS method since 1998 had low enough detection limits to determine if the samples met or exceeded the criteria (Table 20). Prior to the use of ICP-MS, detection limits for cadmium, silver, and nickel were generally higher than the criteria for these metals, and consequently, were not used for criteria comparisons.

Table 19. Summary of Trace Metals Yielded by Three Analytical Methods Compared to Criteria (numbers are percentages)

Metal	Method	% Meeting Criteria	% Exceeding Criteria	% Unknown (Detection limit > criteria)
Cadmium	AAS**	21.7*	4.1	74.1
	ICP	0	0	100
	ICP-MS	100	0	0
Lead	AAS	77.7	7.5	14.8
	ICP	0	0	100
	ICP-MS	96.2	3.8	0
Silver	AAS	6.4	0	93.6
	ICP	0	0	100
	ICP-MS	100	0	0
Copper	AAS	17.3	11.3	71.4
	ICP	99.4	0.6	0
	ICP-MS	80.4	19.6	0
Nickel	AAS	2.9	7.7	89.4
	ICP	0	0	100
	ICP-MS	86.5	13.5	0
Zinc	AAS	99.3	0.7	0
	ICP	95.7	4.3	0
	ICP-MS	96.0	4.0	0
Mercury & Arsenic	AAS	100	0	0
	ICP	100	0	0
	ICP-MS	100	0	0

* All values are percents
** AAS = Atomic Absorption Spectrometer
ICP = Inductively Coupled Plasma
ICP-MS= Inductively Coupled Plasma - Mass Spectrometer

Table 20. Number of Samples Analyzed by ICP-MS Meeting Metal Criteria for Surface Waters

	Lyon		Thornton		Juanita		Swamp		North		Little Bear		Big Bear		McAleer	
Comparison to Criteria	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No
Arsenic	26	0	26	0	24	0	25	0	25	0	26	0	26	0	26	0
Cadmium	6	0	7	0	5	0	6	0	6	0	7	0	7	0	6	0
Copper	27	1	24	3	26	3	26	0	26	0	24	3	27	0	26	1
Lead	80	8	71	21	87	17	64	3	64	2	65	0	62	2	59	13
Mercury	27	0	27	0	27	0	26	0	26	0	27	0	27	0	27	0
Nickel	5	1	7	0	5	2	6	0	6	0	4	3	7	0	5	1
Silver	3	0	3	0	4	0	3	0	3	0	3	0	4	0	3	0
Zinc	26	1	23	4	28	1	26	0	26	0	26	1	27	0	26	1

Most of the AAS generated lead values were viable because the limit of detection was less than the criterion 85% of the time. For the purposes of this report, only the ICP-MS data will be used for comparing sites to each other.

Comparison of the filtered/unfiltered fractions

On a few dates in 1998 and 1999, samples were filtered in order to quantify both the total and dissolved fractions of arsenic, cadmium, copper, lead, mercury, nickel, silver and zinc (Table 21). Neither silver nor mercury was detected in any of the filtered samples collected on those dates. Cadmium was detected in 7 of the 42 unfiltered samples, but not at quantifiable levels (e.g., values were less than the RDL--Run Detection Limit). The remaining metals appear to be associated primarily with particulate matter in stormwater as measurable quantities were greater in unfiltered samples compared to filtered samples.

Table 21. Summary of Levels Found in Unfiltered (Total) versus Filtered (Dissolved) Stormwater Samples Collected in 1998 and 1999[1].

Arsenic	Total	Dissolved		Metal: Ni	Total	Dissolved
n samples	42	41		n samples	42	42
n>RDL	12	3		n>RDL	29	5
average conc. (mg/L)	0.0023	0.0012		average conc.	0.0035	0.0012
Cadmium	**Total**	**Dissolved**		**Metal: Ag**	**Total**	**Dissolved**
n samples	43	42		n samples	24	24
n>RDL	0	0		n>RDL	0	0
average conc. (mg/L)	0.00019	0.00016		average conc.	0.00024	0.00024
Copper	**Total**	**Dissolved**		**Metal: Zn**	**Total**	**Dissolved**
n samples	42	42		n samples	42	42
n>RDL	37	14		n>RDL	42	38
average conc. (mg/L)	0.0045	0.0019		average conc.	0.019	0.005
Lead	**Total**	**Dissolved**		**Metal: Hg**	**Total**	**Dissolved**
n samples	49	42		n samples	42	42
n>RDL	35	1		n>RDL	0	0
average conc. (mg/L)	0.0041	0.0005		average conc.	0.0002	0.0002

1. Samples were collected on May 27, 1998; October 28, 1998; December 7, 1998; February 24, 1999; June 24, 1999; October 9, 1999; and December 6, 1999.

Sediment Metal Concentrations

Sediment samples were collected from sites near the mouths of the streams annually for twelve years (1987-1999) and analyzed for trace metals (Table 22). Currently there are no State criteria for metals in freshwater sediment, therefore the sediment data were compared to the "Possible Sediment Quality Values" as presented in *Creation and Analysis of Freshwater Sediment Quality Values in Washington State* (WSDOE 1997). Cadmium, copper, nickel, and lead were consistently monitored. Mercury has been monitored for ten years, silver for seven, and arsenic for five.

Metal concentrations in the sediment samples were well below State defined "possible threshold levels." However, concentrations were higher in sediments from basins with a history of urbanization. In addition, none of the concentrations exceeded severe effects levels.

Table 22. Average Metal Concentrations (mg/kg dry weight) in Stream Sediments (1987-1998) Compared to "Possible Sediment Quality Values" (WSDOE, 1997).

		Arsenic	Cadmium	Copper	Lead	Mercury	Nickel	Silver	Zinc
Freshwater Sediment Criteria		**40**	**7.6**	**840**	**260**	**0.56**	**46**	**4.5**	**520**
LYON	Average	Detected 1x	Detected 1x	7.2	13.5	0.03	17.3	0.30	49
	Min-Max	5.1	0.072	4.6-13.0	6.1-24.0	ND-0.03	11.5-23.0	0.20-0.40	36-62
THORNTON	Average	5.25	0.04	11.9	37.6	0.041	19.7	0.42	78
	Min-Max	2.5-8.0	ND-0.04	6.7-16.2	20-51	0.03-0.06	15.0-23.0	0.21-1.0	42-94
JUANITA	Average	<detection	Detected 1x	8.0	8.5	0.03	19.0	0.31	43
	Min-Max	ND	0.12	5.8-11.3	4.0-14.0	0.02-0.04	13.5-22.0	0.19-0.40	32-59
SWAMP	Average	Detected 1x	0.15	5.0	5.9	0.02	15.2	0.31	30
	Min-Max	5.0	ND-0.15	3.2-6.8	1.7-14.0	ND-0.02	5.0-25.0	0.20-0.40	20-56
NORTH	Average	5.8	Detected 1x	5.7	4.5	0.015	16.3	0.31	33
	Min-Max	2.4-9.2	0.05	3.8-10.0	ND-8.0	.01-.02	12.0-22.0	0.19-0.40	21-76
LITTLE	Average	Detected 1x	0.23	4.9	3.6	<detection	18.1	0.31	30
BEAR	Min-Max	6.0	ND-0.3	3.5-5.9	ND-5.0	ND	10.8-31.0	0.19-0.40	25-38
BEAR	Average	Detected 1x	0.20	3.8	3.6	<detection	15.5	0.31	26
	Min-Max	7.1	>2-ND	2.2-8.1	ND-5.0	ND	11.0-20.0	0.20-0.40	17-36

Arsenic

The concentrations in the 35 samples analyzed ranged between 2.4 mg/kg and 9.2 mg/kg but most were between 2.5 and 5.0 mg/kg, well below the proposed threshold value of 40mg/kg.

Cadmium

Cadmium was found at measurable levels in 16 of the 88 samples analyzed. The concentrations in those samples ranged from 0.04 and 0.05 mg/kg, well below the proposed threshold of 7.6 mg/kg. Four of the five highest concentrations were found in Thornton Creek samples.

Copper

The levels found in the 84 samples analyzed ranged from 2.2 to 16.2 mg/kg but most were between 4.3 and 7.8 mg/kg. The proposed sediment quality value for copper was 840 mg/kg. The highest levels measured in 10 of the 12 years were in samples from Thornton Creek.

Lead

Lead was found at measurable levels in 50 of the 84 samples analyzed. The concentrations ranged from 2.7 mg/kg to 51 mg/kg but most were between 5 and 22 mg/kg, well below the proposed sediment threshold of 260 mg/kg. The highest level measured each year was in the Thornton Creek samples.

Mercury

Mercury was in measurable levels in ten of the 71 samples analyzed. Levels ranged from 0.01 to 0.06 mg/kg. Mercury was detected in 14 other samples and undetectable in the rest. The proposed sediment quality value for mercury is 0.56 mg/kg.

Nickel

Nickel was found in measurable levels in all of the 84 samples analyzed. The concentrations ranged from 5 to 31 mg/kg but most were between 15 and 20 mg/kg. The proposed sediment quality value for nickel is 46 mg/kg.

Silver

Silver was undetectable in 42 of the 51 samples analyzed, detected but not measurable in 2 and measurable in seven. The concentrations in those 7 samples ranged from 0.3 and 1.0 mg/kg, well below the proposed threshold of 4.5 mg/kg.

Zinc

Zinc was found at measurable levels in all 84 samples analyzed. The concentrations ranged from 17 mg/kg to 94.2 mg/kg but most were between 24 and 47 mg/kg, well below the proposed threshold of 520 mg/kg. The highest levels were found in Thornton Creek samples eleven of the twelve years monitored.